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A Guide to Arctic Field Trips

Ronald I Verrall

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Abstract

For more than thirty years scientists and technicians from the Defence Research Establishment Pacific (now defunct) went to the High Arctic to do underwater acoustics research. During these years they developed many tricks and techniques for living and working on sea ice, and this document describes many of them There are sections on transportation, safety and coping with the cold. Part of the document discusses sea ice: how to gauge its age and thickness, and how to establish temporary camps on it. A large section discusses the many ways of making and maintaining holes through the sea ice - with both mechanical drills and hot-water drills. Another section describes a number of techniques for installing equipment through the ice and getting it back. The manual describes in some detail the use of equipment such as snowmobiles, tracked vehicles, gas- and Diesel-powered generators, HF radio, VHF radio, repeaters, stoves, hot-water drills and remotely operated underwater vehicles.

Résumé

Pendant plus de trente ans, les scientifiques et techniciens du Centre de recherches pour la défense (Pacifique) (maintenant aboli) se sont rendus dans l'extrême Arctique pour y mener des recherches en acoustique sous-marine Au cours de cette période, ils ont mis au point un grand nombre d'astuces et de techniques leur facilitant la vie et le travail sur la glace de mer dont plusieurs sont décrites dans le présent document On y trouve des sections sur les transports, sur la sécurité et sur la manière de vivre avec le froid. Dans une partie du document on traite de la glace de mer : comment en apprécier l'âge et l'épaisseur ainsi que comment y établir des camps temporaires. Une longue section aborde les nombreuses manières de percer et de garder ouverts des trous dans la glace, au moyen de foreuses mécaniques et de foreuses à eau chaude. Dans une autre partie, on discute un certain nombre de méthodes permettant d'installer de l'équipement à travers la glace et de le récupérer. Ce manuel décrit de manière détaillée l'utilisation de pièces d'équipement comme les motoneiges, les véhicules à chenilles, les génératrices à essence et au Diesel, les radios à ondes décamétriques, les radios à très haute fréquence, les répétiteurs, les poêles, les foreuses à eau chaude et les véhicules sous-marins télécommandés.

Executive summary

INTRODUCTION:

Scientists and technicians from the Defence Research Establishment Pacific (DREP) carried out underwater acoustics research in the High Arctic from the late 1950's until 1998. During that time they developed equipment and techniques for living comfortably in small camps on the ice of the Arctic Ocean and for successfully carrying out their under-ice research. This document is a manual describing their methods. It has been written because DREP was closed as a separate entity in 1994, and almost everyone with Arctic experience has left the government service. It is an attempt to preserve some of the corporate memory

SUMMARY OF DISCUSSION:

The document starts by describing the Arctic - its size, its extent, temperatures, length of day, etc. It then discusses the sea ice to be found in the Arctic - the differences between annual ice, multi-year ice, shelf ice, ice islands, etc., and where these different types of ice are to be found.

A discussion of work in the Arctic begins with a description of the various forms of transportation: getting to the Arctic, transportation out to the ice and transportation on the ground. This section describes what to look for when a landing on sea ice is required. It also describes techniques for smoothing, marking and otherwise improving the 'runway'. The discussion of 'Ground Transportation' describes the advantages and disadvantages of various types of snowmobile, and it talks about the many types of sled that the group has designed and built.

The next section describes the techniques that have been developed for living and working in the Arctic. First, there is a discussion of clothes and keeping warm. Next is a description of how Arctic tents are set up on the ice and how they are anchored down. Stoves and fuels are discussed. Sleeping arrangements, food and cooking, water, sanitary facilities and communications are then discussed in some detail. A section on safety discusses the various dangers, especially those unique to the Arctic.

The next major section describes techniques for making holes through the ice. Several historical methods are discussed, such as chain saws, axes and explosives. Then follows a description of various types of auger drills, both powered and unpowered. Following this is a section on the DREP hot-water drill - its design history, its operation, and the use of hot water to make holes, both large and small. Following this is a short discussion on how to recognize thin ice.

The next section is about the deployment and recovery of equipment. Part of this is a discussion on lowering and raising heavy gear, part of it is about keeping ice holes open and part is about methods of releasing weights from the equipment that is being lowered. This is followed by comments on installing cables safely across the foreshore and a discussion on remotely operated vehicles (ROV's).

The document concludes with a discussion of miscellaneous equipment: gasoline and Diesel engines, various heaters, ropes, tools and the problems of navigating and surveying.

SIGNIFICANCE OF RESULTS:

This document will be very useful if the Department of National Defence decides to maintain a research capability in the Arctic. There is virtually no one left with any depth of experience in Arctic research work.

FUTURE PLANS:

Because of warming trends thinning the ice in the Arctic and because of an American ship passing through the Northwest Passage in the summer of 2000, Canada is once again becoming concerned about northern sovereignty. Interest in the Arctic will probably increase for the next five or six years. In the immediate future a DRDC Technology Demonstration Project on rapidly deployable systems is scheduled to make an Arctic deployment in the spring of 2002.

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Sommaire

INTRODUCTION:
Les scientifiques et techniciens du Centre de recherches pour la défense (Pacifique) (CRDP) ont exécuté des recherches en acoustique sous-marine dans l'extrême Arctique de la fin des années 50 jusqu'en 1998. Pendant cette période, ils ont mis au point un grand nombre de pièces d'équipement et de techniques leur permettant de vivre confortablement dans de petits camps sur la glace de l'océan Arctique et de mener à bien leurs recherches sous la glace. Ce document est le manuel décrivant leurs méthodes. Il a été rédigé parce que le CRDP a fermé ses portes en tant qu'entité distincte en 1994 et parce que presque tout le personnel possédant une expérience de l'Arctique n'est plus à l'emploi du gouvernement. On tente d'y conserver une partie de la mémoire de l'organisation.

RÉSUMÉ DE LA DISCUSSION:
Le document débute par une description de l'Arctique – taille, limites, températures, durée du jour, etc. On y aborde ensuite la glace de mer présente dans l'Arctique – différences entre glace annuelle, glace de plusieurs années, plateau de glace, île de glace, etc. et les endroits où on les trouve. La discussion des travaux dans l'Arctique s'ouvre sur les divers moyens de transport utilisables : se rendre dans l'Arctique, transport jusqu'à la glace et transport au sol. Cette section décrit les aspects à prendre en considération lorsqu'il est nécessaire d'atterrir sur la glace. On y décrit également les techniques permettant d'aplanir, de marquer et d'améliorer par ailleurs la «piste». La discussion sur les «transports au sol» aborde les avantages et les inconvénients de divers types de motoneiges ainsi que d'un grand nombre de types de traîneaux que le groupe a conçu et fabriqué.

Dans la section suivante, on décrit les techniques mises au point pour vivre et travailler dans l'Arctique en commençant par les vêtements nécessaires pour se tenir au chaud. Vient ensuite une description de la manière d'installer les tentes arctiques sur la glace et de les ancrer. Les poêles et les combustibles sont traités. Les dispositions pour le sommeil, les aliments et la cuisson, l'eau, les installations sanitaires et les communications sont ensuite abordés de manière détaillée. Une section traite de la sécurité et des divers dangers, surtout ceux qui sont particuliers à l'Arctique.

La section suivante décrit les techniques permettant de pratiquer des trous dans la glace. Plusieurs méthodes historiques sont exposées comme celles faisant intervenir des scies à chaîne, des haches et des explosifs. On présente ensuite une description des divers types de tarières motorisées et manuelles, avant de décrire la foreuse à eau chaude du CRDP, l'histoire de sa conception, son fonctionnement et l'utilisation d'eau chaude pour le forage de gros et de petits trous. On explique brièvement comment reconnaître la glace mince avant de passer à l'installation et à la récupération d'équipement. Une partie de cette explication est consacrée à l'abaissement et au soulèvement de matériel lourd, une autre à la façon de garder ouverts les trous dans la glace et une autre encore aux méthodes permettant de relâcher les poids fixés à l'équipement abaissé. On formule ensuite des commentaires sur l'installation en toute sécurité de câbles traversant l'estran qui sont suivis d'une discussion des engins télécommandés. En conclusion, on présente une discussion de diverses pièces d'équipement, moteurs à essence et

Diesel, divers appareils de chauffage, cordes et outils, ainsi que des problèmes que posent la navigation et les levés.

IMPORTANCE DES RÉSULTATS:
Ce document sera des plus utiles si le ministère de la Défense nationale décide de gérer une installation de recherche dans l'Arctique. Il ne reste pratiquement plus personne possédant une grande expérience des travaux de recherche dans l'Arctique.

PROJETS:
En raison de l'amincissement de la glace dans l'Arctique en réponse à la tendance au réchauffement et de la traversée du passage du Nord-Ouest par un navire américain à l'été de l'an 2000, le Canada se préoccupe de nouveau de la question de la souveraineté dans le Nord. L'intérêt pour l'Arctique augmentera probablement au cours des cinq à six prochaines années. Dans l'immédiat, un déploiement dans l'Arctique de systèmes à mise en place rapide est projeté pour le printemps de 2002 dans le cadre du Programme de démonstration de technologies de RDDC.

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Dedication

This document is dedicated to the memory of David G. Baade, a technologist who worked for many years with the Arctic Acoustics Group at the Defence Research Establishment Pacific. Dave suggested and developed many of the inovative techniques described here, and he improved many of the ideas suggested by others. Without him, we probably would have worked harder and suffered more, and we definitely would have achieved far less.

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A Guide to Arctic Field Trips

1.0 Introduction

Many of the scientists and technicians of the Defence Research Establishment Pacific (DREP) have had the unique opportunity of doing under-ice research in the High Arctic. Almost every spring since the late '50s someone from DREP has set up an ice camp somewhere in the Arctic. During the '70s it was on the ice of the channels, and later it was on the Arctic Ocean itself. During this time they accumulated much experience in the rather specialized techniques of living and working on the ice.

With the occasional brief exception[1], this sort of practical knowledge is seldom written up. This is partly because techniques are always evolving and changing, and partly because the information is not 'scientific research' in the pure sense, and the participants are not motivated to find the time to write it down. New ideas and techniques are discussed only informally in meetings and in bars, and usually only with other Arctic workers. The more mundane skills of living, working and making equipment work in the Arctic are seldom mentioned except to the occasional new person in the group - someone who has an immediate requirement for the knowledge. Thus, when an 'Arctic' group disbands, much of this knowledge is lost, and a new group that wishes to start work in the North must reinvent a lot of wheels.

This document has been written because the Arctic group at the Defence Research Establishment Pacific (DREP) has, in fact, been disbanded, and nearly all the experienced people are gone. It is intended as a primer for setting out research camps in the Arctic and for doing oceanography from these ice camps. It talks about clothes, camps and transportation. It discusses how to cope with the weather and with the sea ice. It describes a variety of techniques for putting equipment through the ice and for getting it back. Ultimately, of course, only experience can teach a person the hundreds of small but necessary things that he or she will need to know, but, hopefully, this will be a start.

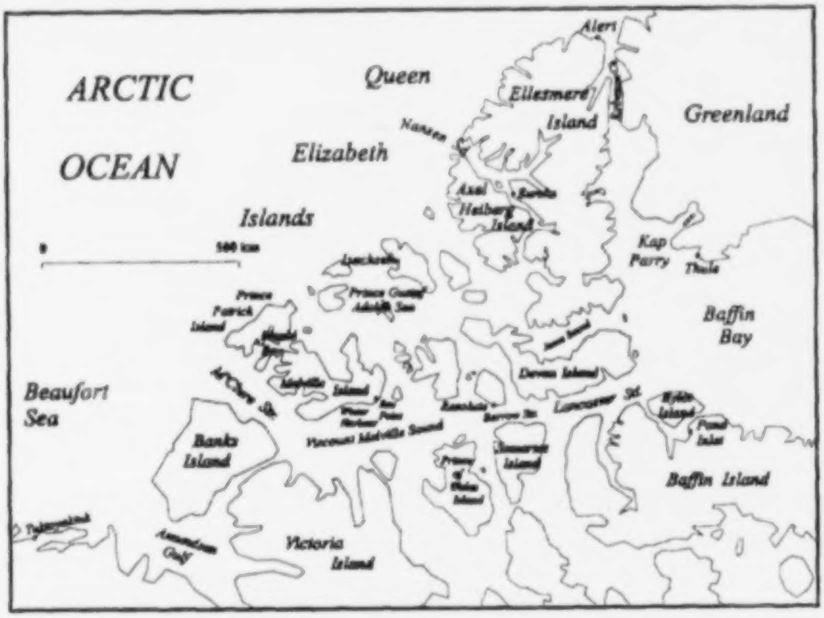
Many of the techniques discussed here are a consequence of DREP's particular problems and experiences. Other Arctic locations and other types of fieldwork will have their own special difficulties, but a great deal of DREP's knowledge and experience will be applicable to all scientific work in the Arctic.

2.0 The Arctic – A Description

2.1 Location

The Canadian Arctic is a vast area (Figure 1). Roughly speaking, it forms a triangle extending from the Arctic Circle (at 66° 34' N) north to the northern tip of Ellesmere Island (at 83° 07' N), a north-south distance of 1000 nautical miles (nm) or about 1860 km. It reaches from the eastern coast of Ellesmere Island and Baffin Island at about 61° 10' W to the western boundary of the Yukon at 141° W, and this represents a longitude range of five and a half time zones. The east-west distance along the Arctic Circle is 1900 nm or about 3500 km.

The High Arctic is extremely remote from southern centres. Most southerners consider Yellowknife to be fairly far north (62° 27' N) and quite remote, but its great-circle distance from Victoria, B.C., is only 1660 km, whereas the distance from Victoria to Resolute Bay on Cornwallis Island is 3230 km, nearly twice as far. The distance from Victoria to CFS Alert at the northern tip of Ellesmere Island is 4300 km, so that when a Hercules aircraft from Victoria arrives at Yellowknife to refuel, it is only nicely past one third of the way to Alert. This distance of 4300 km is comparable to that between Victoria and Halifax, which is 4500 km by great-circle route.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Adolf Sea
Baffin
Bay
Devon Island
Beaufort
Sea
M'Clure St.
Melville
Island
Resolute
Barrow St.
Lancaster Sd.
Bylot
Island
Pond
Inlet
Banks
Island
Viscount Melville Sound
Somerset
Island
Prince
of
Wales
Island
Baffin Island
Tuktoyaktuk
Amundsen
Gulf
Victoria
Island

FIGURE 1. A map of Canada's north with emphasis on the Arctic Archipelago.

2.2 Climate

There may be many misconceptions about the Arctic, but its cold is very real. Even during the spring months of March, April, and well into May the average temperature is well below the freezing mark. Table 1 gives temperature statistics for several locations in the Arctic. (These are Environment Canada's figures, and can be found at the web site:
http://www.cmc.ec.gc.ca/climate/normals/eprovwmo.htm)
The daily minimum, the daily mean and the daily maximum are given for each month. For comparison, the average daily temperatures in Winnipeg and Edmonton during January, their coldest month, are -18.3 and -14.2° C, respectively, which are about 18° and 22° C warmer than Eureka. And these are cities that take a perverse pride in how cold it gets!

TABLE 1. Daily minimum, mean and maximum temperatures for several locations in the High Arctic. (Degrees Celsius)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alert (1950 - 1990)												
Daily Min.	-35.7	-37.4	-36.8	29.0	-14.7	-3.4	0.6	-1.7	-12.9	-23.2	-30.7	-33.4
Daily Mean	-31.9	-33.6	-33.1	-25.1	-11.6	-1.0	3.4	1.0	-9.7	-19.5	-27.0	-29.5
Daily Max.	-28.3	-29.9	-29.4	-21.3	-8.7	1.3	6.1	3.6	-6.6	-16.0	-23.5	-25.8
Eureka (1947 - 1990)												
Daily Min.	-40.3	-42.0	-40.9	-32.2	-14.5	-0.7	2.4	0.6	-11.4	-26.1	-35.6	-38.1
Daily Mean	-36.6	-38.4	-37.4	-28.0	-10.9	1.9	5.4	3.0	-8.4	-22.3	-32.0	-34.5
Daily Max.	-33.1	-35.0	-34.1	-23.9	-7.6	4.4	8.4	5.4	-5.5	-18.6	-28.6	-31.0
Mould Bay (1948 - 1990)												
Daily Min.	-37.2	-38.5	-36.0	-28.5	-14.4	-2.4	1.1	-1.1	-9.0	-21.4	-30.6	-34.4
Daily Mean	-33.4	-34.7	-32.3	-24.3	-11.1	0.0	3.9	1.2	-6.4	-17.8	-26.9	-30.7
Daily Max.	-29.7	-31.1	-28.7	-20.3	-7.9	2.4	6.5	3.4	-3.9	-14.3	-23.4	-27.1
Resolute Bay (1947 - 1990)												
Daily Min.	-35.8	-36.7	-34.9	-27.3	-14.3	-2.9	1.3	-0.5	-7.3	-18.5	-27.9	-32.7
Daily Mean	-32.0	-33.0	-31.2	-23.5	-11.0	-0.6	4.0	1.9	-5.0	-15.2	-24.3	-29.0
Daily Max.	-28.5	-29.4	-27.7	-19.9	-7.9	1.6	6.8	4.3	-2.8	-12.1	-20.9	-25.5

Because of the long period of intense cold, the ocean freezes over. In a single year the sea will thicken to about 1 to 2 m (4 to 7 ft), and multi-year ice can be much thicker than this. Ice floes that are 6-m (20-ft.) thick are common, and 9-m (30 ft) floes are not uncommon.

Moreover, ice ridges can often be 15 to 25 m (50 to 80 ft.) thick. It is the cold and the ice cover that make the problems of doing oceanography in the Arctic so unique

Although most people know about the cold in the Arctic, many southerners are only vaguely aware of the long summer days and winter nights. Arctic residents say that the long winter night is hard to cope with psychologically, and in some respects it is worse than the cold.

At the spring equinox, 21 March or thereabouts, the sun is above the horizon for 12 hours and below the horizon for 12 hours. This, of course, is true everywhere. After the March equinox the days in the northern hemisphere begin to lengthen, and in the far north they lengthen very quickly. At CFS Alert, for example, the sun is up 24 hours per day only three weeks after the equinox, and it stays up until three weeks before the fall equinox. These long days are very useful for research work in the summer.

With regard to climate, another important feature is the dearth of precipitation. Many of the High Arctic islands receive less than 100 mm (4 in) of rain (or equivalent) per year.

3.0 Sea Ice

3.1 Problems of Working on Sea Ice

The practical problems of doing oceanography in the Arctic are very different from those of the other oceans, and, although one factor is the extreme cold, the principal difference is the ice cover. The whole of the Arctic is inaccessible by ship for much of the year, and a good percentage of it is never accessible by ship. For the most part, therefore, the physics of the ocean must be studied from camps set up on the ice. It is important to recognize that to do successful science one must identify and overcome the problems caused by the ice cover. It is also important to use any advantage the ice might provide.

The disadvantages of the ice are fairly obvious:

1. Heavy ice prevents access by ship to the area of interest.
2. Ice restricts one's ability to put sensors and other equipment into the ocean. This is probably the most serious problem.
3. Related to the above is the difficulty of laying cable on the ocean bottom and of bringing it ashore.

On the other hand, there are several advantages:

1. Oceanographic experiments that are set out on the ice are often less expensive than those that must be supported by a ship.
2. Geometries are stable. It is easy to maintain equipment at a constant position and at a constant depth. Vertical heave of the sensor is not a problem.
3. Large areas can be used to set out arrays of sensors. Their relative spacings can be made very accurate and very stable. Their absolute locations are fixed as long as the ice is unmoving, and this is true whenever the ice is shore-fast.
4. Remote sensors can be left anchored in the ice for long periods without their drifting out of the area of interest.
5. The ice constitutes a strong deck onto which one can fasten winches and capstans.
6. No one gets seasick.

3.2 Ice Types and their Recognition

To take maximum advantage of the ice it is important to know and recognize the various ice types, ages and thicknesses. There is an extensive nomenclature given to sea ice. See, for example, the web page supported by the Canadian Ice Service (Environment Canada) http://www.tor.ec.gc.ca/ice/about/term.html (at the time of writing). Table 2 is taken from this web site and gives their nomenclature.

For our purposes, the important ice parameters pertain to the safety of landing an aircraft on the ice, to the safety of the subsequent ice camp, and to the ease of getting equipment into the water beneath. In this regard, the most important variable is the thickness of the ice. The other important characteristics are the roughness of the ice and the likelihood that the ice will drift or break up, and these characteristics are dependent to some extent on the thickness of the ice. Therefore, when one is flying over the ice looking for a place to set up a camp, it is important to be able to recognize the age and thickness of the ice. The following is a discussion of the basics of how the ice forms and how it changes in thickness, structure and roughness as it gets older. (For a detailed description of the formation and the properties of sea ice see, for example, Pounder[2] or Doronin and Kheisin[3].)

Ice that has formed from scratch during the current ice season is known as annual ice or first-year ice. In particularly cold areas it will thicken to 2 m (6 ft.) during the course of the winter and spring. In warmer areas, or in places such as eastern Barrow Strait and

Lancaster Sound (Figure 1), where the westerly winds and currents carry the ice out of the region until late in the fall, the ice will not grow nearly as thick.

TABLE 2. Nomenclature of Sea Ice

Name	Description
New	A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals, which are only weakly frozen together (if at all), and have a definite form only while they are afloat.
Grey	Young ice 10-15 cm thick. Less elastic than nilas (new, smooth ice) and breaks on swell. Usually rafts under pressure.
Grey-white	Young ice 15-30 cm thick. Under pressure it is more likely to ridge than to raft.
Thin first-year	First-year ice of not more than one winter's growth, 30-70 cm thick.
Medium first-year	First-year, ice 70-120 cm thick.
Thick first-year	First-year ice over 120 cm thick.
Old ice	Sea ice that has survived at least one summer's melt. Topographic features generally are smoother than first- year ice. May be subdivided into second-year ice and multi- year ice.
Second-year ice	Old ice which has survived only one summer's melt
Multi-year ice	Old ice which has survived at least two summer's melt.

Ice that has lasted through the following summer and is putting on its second year of growth is known as second-year ice, and it may grow to a thickness of 3.6 m (12 ft.). Ice that is older than two years is not given a yearly name since older ice changes less and less every year. Even second year ice is hard to distinguish from older ice. Usually, all the old ice is known as multi-year ice.

The first step in recognizing the age and thickness of the ice is to know what types of ice are usually found in the area of interest. In Barrow Strait, Lancaster Sound or Jones Sound, for example, nearly all the ice either melts or 'goes out' into Baffin Bay during the summer. Consequently, the ice must form anew every year, and, therefore, nearly all the ice will be annual ice. On the other hand, in the Arctic Ocean proper the ice may last for many years before it escapes to the south down one side of Greenland or the other. Thus, much of the Ocean is covered by old, multi-year ice.

The ice atlases published by the Canadian Ice Service (Environment Canada) show the types of ice found in the different regions of the Canadian Arctic. The maps indicate the percentage of each type of ice at various times of the year. The Pilot of Arctic Canada[4] (published by the Department of Energy, Mines and Resources) gives a good written description of the ice in each area.

Armed with the knowledge of what sort of ice to expect, one first looks at the colour of the ice and its roughness. Very thin first-year ice is almost black, and it progresses through grey to white as it gets thicker. Table 2 gives various names to these stages, but knowing the names are not as important as the ability to recognize ice that is too thin for an aircraft to land on. Black and grey ice are definitely too thin, but that is not to say that a white surface is safe. Beware, especially, a fresh layer of snow hiding the darker colour of thin ice. Moreover, if there are snowdrifts everywhere except for the nice smooth snow where you plan to land, you might consider that the ice has formed since the last wind storm. In other words, the ice may be new and much too thin. The pilot knows all these things (and probably lots more), so he will likely not land on thin ice, but he is human, and mistakes involving snow-covered thin ice have happened.

Large areas of annual ice, such as are found in Barrow Strait or Jones Sound, consist of smooth, flat areas interspersed with ridges of ice that have been caused by the wind putting the ice under compression. The distance between the ridges will typically be somewhere between 30 m and 500 m, depending on the thickness of the ice when it was compressed and how much fetch was available for the wind to build up pressure. The ridges will be composed of blocks of ice that are very rough and distinct; they have a different look than blocks of second-year ice which have been smoothed by a summer's melt and which are perhaps melded together. Second-year or multi-year ice may also show a blue colour if the snow has been blown off the ice. The occasional floe of second-year ice in Barrow Strait will sometimes stand out very clearly because of the colour and the smoothed-over ridges. In this regard, remember that the sharp ridges of annual ice may well look smooth because of drifted snow. To see the roughness, look for places where the snow has been blown away. Try to visualize the ice with the snow stripped off.

The pack ice in the Arctic Ocean has had a much different history than the annual ice in the Arctic channels. Looked at from the air, the surface is composed of large rafts of old ice known as pans or floes. These pans range in size from, say, a hundred metres in diameter to several km in diameter (Figure 2). The ice in the floes is usually many years old. The early explorers (Nares[5], for example) called them paleocrystic floes because of their apparent age.

In the summer, these pans are generally free to move relative to each other. In areas of the Arctic where the ice tends to converge, such as north and west of Ellesmere Island, the pans bump against each other in the summer as they are pushed around by the wind. This contact knocks off the rough corners, and the pans become quite rounded. In areas where the ice does not converge, such as the region of the North Pole, the floes are not subjected to this grinding action, and they remain angular and jagged in shape.

In the winter, the old floes become surrounded by new ice. This annual ice, even at a thickness of 4 or 5 ft., is relatively thin and easily crushed between two pans of heavy old ice. After crushing the thin ice, the floes will then often separate and let new ice form. The back-and-forth 'pumping' action between two floes can generate large quantities of new ice which gets piled into rubble and ridges (Figure 3). This action can generate thick ice, and it appears to be one of the principle ways in which new thick ice is formed.

FIGURE 2. Circular pans of multi-year ice drifting south in Robeson Channel during the late summer. The camera is facing northwest and is looking at the cliffs along the Ellesmere Island.

Two pans that are pressed together will sometimes freeze in place and trap the ridge of new ice that has formed between them. Evidence of these ridges can be seen in every floe of reasonable size, and the ridges range in age from the brand-new ones where the ice blocks are still jagged to old rolls which have been smoothed and rounded by years of summer heat. Sometimes they have been almost completely ablated, and only the linearity of the feature makes it visible to the human eye. Figure 4 shows ridges that are at least

FIGURE 3. Crushed sea ice in an active area. Although fairly large pans of old ice can be seen, most of the ice is ground-up annual ice.

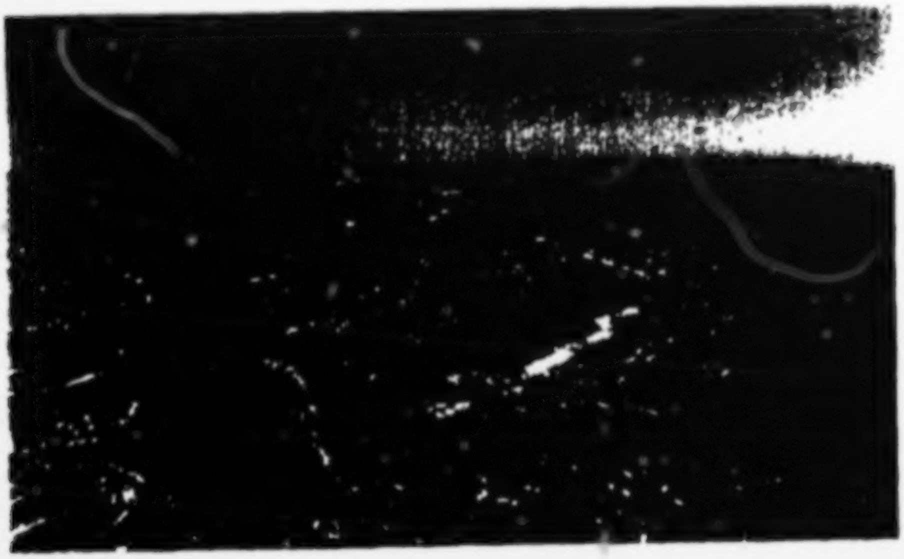

FIGURE 4. Old Ridges can be seen running through the pans of ice.

a year old running through some round pans of ice. One can often see ridges of different ages crossing in the centre of a floe, and it is of interest (in an otherwise boring Twin Otter flight) to speculate as to the history of the various floes.

A large pan that is bisected by old 'fossil' ridges is usually considered to be very old and thick and, therefore, safe for a camp. The (perhaps wishful) thinking is that 'if it has lasted that long, it will probably last another year'. A pan that has a fairly new ridge running through it is deemed thin, weak and unsafe. Again, this is based more on folklore than on any long-term observations.

We have discussed the processes that cause floes to become larger. There are, of course, competing mechanisms that make the floes smaller. As mentioned before, there is often a grinding action between adjacent floes that knocks off sharp corners and makes the pans more rounded. A more dramatic breakage is caused by the large shear forces that are generated in close-packed ice (presumably by distant winds). Under these forces the ice will shear - forming a crack that will sometimes extend for many kilometers. The shear cracks are remarkably straight, and they seem to accord no more respect to the heavy old floes than they do to new, annual ice. One would intuitively think that a crack would skirt round an old floe and follow the thinner and weaker ice at its edge. This might well happen if the crack were opened by tension forces, but cracks formed by shear will pass through the heaviest of floes. (This, of course, contradicts the theory that old floes are safe.) Once an old floe has been split in two by shear, each side begins life anew as a separate but smaller floe.

After the shear has sliced through the pan, the two pieces of ice will sometimes drift apart leaving a long, narrow, fairly straight stretch of open water. This is called a 'lead'. The word was used originally by early whalers and other northern mariners. It implied that the long channels of open water would 'lead' the ships into or through the pack ice.

In the spring the Arctic pack ice is riddled with refrozen leads of various lengths, widths and thicknesses, although in areas of strong convergence they are not so plentiful. Usually the ice that covers them is smooth, which makes them a prime candidate for an aircraft landing strip. On the other hand, the ice in the lead is sometimes undulating with a wavelength of several metres. These waves are produced when the ice is quite new and thin. The new ice, which is quite saline, is very flexible, and when it is compressed by heavy neighbouring ice it flexes like wrinkled skin. If the strain is held constant for long enough, the surface waves will be literally frozen in place as the ice thickens (Figure 5).

Because of the somewhat traumatic way in which the thick old floes are formed and because of the yearly melting and refreezing of their surface, they are seldom smooth on the surface. At best the surface is rolling, and at worst it is extremely rough and jagged. The occasional exception to this is the refrozen melt pool which, if large enough, can be spotted from the air. A melt pool forms when the surface of a large pan melts during the summer, forming a lake on the surface of the ice. When the water freezes, a large smooth patch of ice is the result. They are not common since the melt water that forms on a floe usually drains down through a crack into the ocean and never gets a chance to form a lake. However, although melt pools are fairly rare, they are of particular interest since they are good candidates for aircraft landing strips.

FIGURE 5. Thin ice (in the foreground) that has been pushed into wrinkles by external pressure.

It is interesting to note that the ice on the underside of a floe stays quite rough even though the surface relief decays with time. The ice as seen from below by a video camera looks like it has not changed at all from the time it first formed. There is no mechanism similar to the sun's heat that will smooth the edges of the ice blocks at the bottom of the ridge. At one ice camp we drilled holes through the ice at two points only about 30 m apart. At one hole the ice was 10 m thick, and at the other the ice was only 5.2 m thick. Although the floe was obviously old, the surface was only gently undulating, and there were no particular clues that would suggest such an impressive variation in thickness.

Along the north coast of Ellesmere Island there are many semi-enclosed bodies of water where the ice formations are permanent, the ice never 'going out'. This type of ice has different names in different places. The permanent ice is called a 'plug' in Nansen Sound, which is the body of water between Ellesmere Island and Axel Heiberg Island (Figure 6). In the northern 50 nautical miles of the Sound the ice has grown to a thickness of 5.5 to

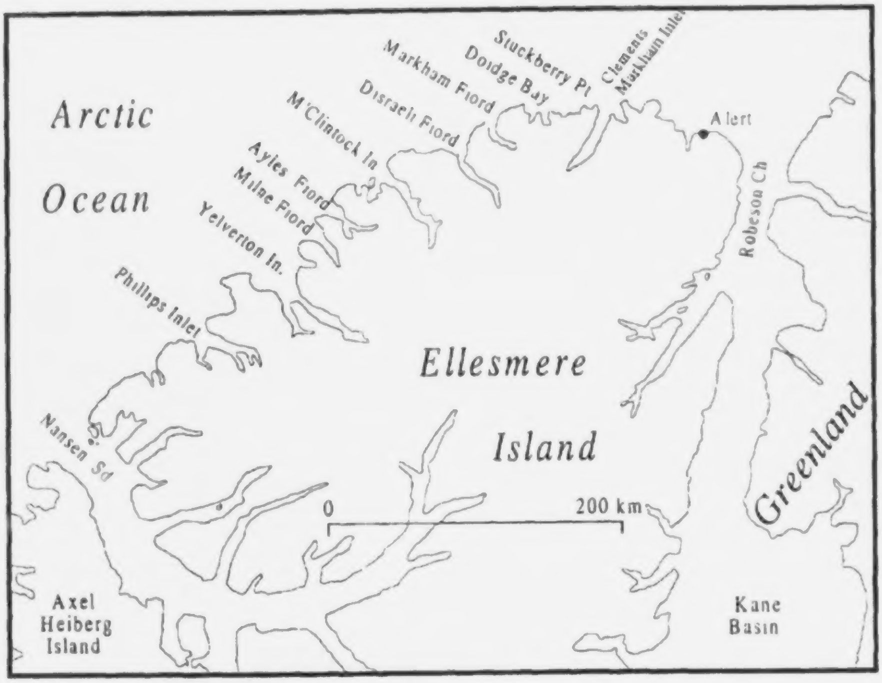
Arctic
Ocean
Stuckberry Pt
Clements Markham Inlet
Markham Fiord
Doidge Bay
Disraeli Fiord
M'Clintock In
Ayles Fiord
Milne Fiord
Yelverton In.
Phillips Inlet
Alert
Robeson Ch
Ellesmere
Island
Nansen Sd
0
200 km
Greenland
Axel
Heiberg
Island
Kane
Basin

FIGURE 6. A map of northern Ellesmere Island showing the major inlets along the north coast.

6 m, and it is so thick and strong that it can be held in place by the surrounding land formations just as a filling is held by a tooth. The surface ablates (by melting) in the summer, but the ice seldom moves out of its fixed position. At one time we thought that it never moved at all, and we considered using the ice as a permanent platform for hydrophones. In 1980 we lowered sensors through the ice near the northern edge of the plug and cabled the sensors to a small hut set on stilts in the ice. The ice did not, in fact, move during the first two summers after the installation, but during the summer of 1982 the ice broke into a number of large chunks and shuffled around a little. There was no large-scale movement, but there was enough motion to rotate our hut and our array of sensors quite appreciably.

The ultimate thickness of the plug is determined by how much ice melts during the summer and how much ice can freeze to the bottom of the plug each winter. During the summer, about 0.5 m of the surface ice melts and runs down cracks or holes in the ice. If the ice is at its equilibrium thickness, the same amount of new ice will form at the bottom of the plug during the winter. This equilibrium thickness is about 6 m. An early description of the plug is given by Serson[6], and the plug is discussed in greater detail by Sadler and Serson[7]. Figure 7 shows a small building mounted on wooden piles in the ice of the Nansen Ice Plug. The left-hand picture shows the building when it was first installed. The right-hand picture shows the building after two summers of melting. The ice surface has pulled away from the building.

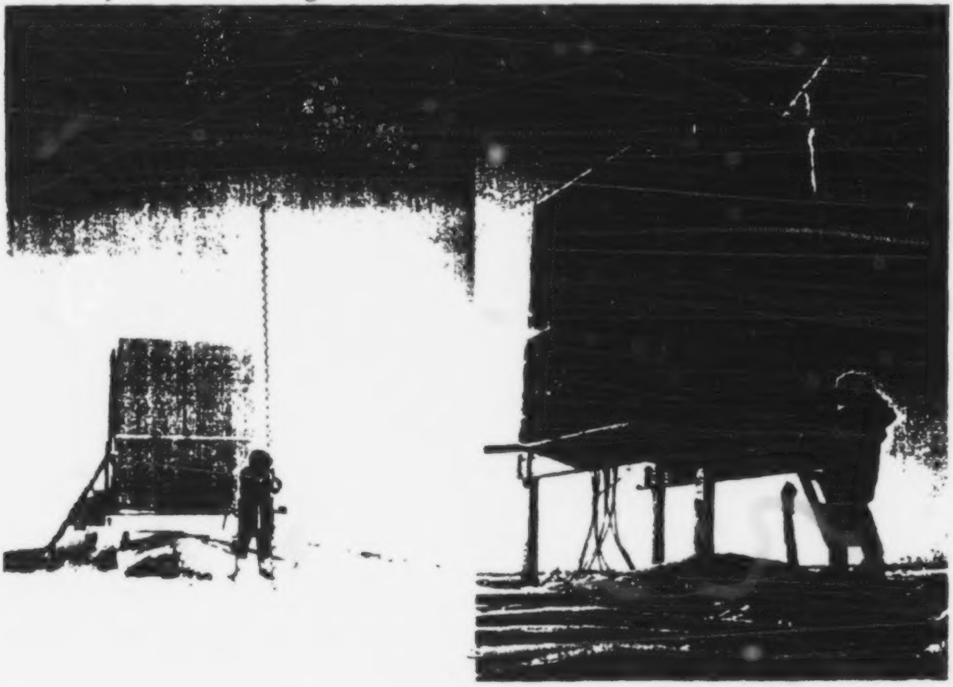

FIGURE 7. A building mounted on stilts in the ice of Nansen Sound. On the left is the building when it was first installed. The length of the drill corresponds to the thickness of the ice. The right-hand picture shows the building after two years of ice ablation. To stabilize the building it was lowered down the posts, and the posts were set deeper into the ice.

At other inlets and fiords along Northern Ellesmere Island the bodies of semi-permanent ice are called ice shelves. The largest of these is the Ward Hunt Ice Shelf, which spreads out from the mouth of Disraeli Fiord (Figure 6). The other major ones are the Milne Ice Shelf, the Ayles Ice Shelf, the Markham Ice Shelf and the Alfred Ernest Ice Shelf, which is just southwest of Nansen Sound. There are other, smaller shelves, which are not associated with glaciers and which are called Multiyear Landfast Sea Ice (MLSI) in the literature[8]. Examples are found on the bays on both side of Stuckberry Point, at Doidge Bay and on the bay near Moss Point, which is between Stuckberry and Doidge.

The thickness of the Milne Ice Shelf[9] ranges from about to 10 m to 100 m, and that of the Ward Hunt Shelf is about 45 m The ice on the MLSI at Stuckberry is about 5 to 6 m.

The surface of the shelf ice is characterized by undulations or 'rolls'. At the Ward Hunt Ice Shelf, the distance between these rolls is about 200 to 300 m and the amplitude of the rolls from bottom of trough to top of rise is 3 to 6 m. On the thinner shelves, the wavelength and the amplitude of the rolls are less. There are several theories pertaining to the source of these rolls, but the generally accepted one is by Hattersley-Smith[10], which suggests that the rolls develop by the action of the along-shore wind extending melt pools into long parallel lakes. Figure 8 shows the large rolls of the Ward Hunt shelf in the spring, and Figure 9 shows the shorter wavelength rolls of Doidge Bay during late summer.

FIGURE 8. Looking eastward along the Ward Hunt Ice Shelf The Arctic pack ice can be seen to the left of the regular rolls.

Every so often, a piece of an ice shelf will break off and float around the Arctic Ocean for several years before it makes its way south. These chunks are known as ice islands. They can be recognized from the air by their enormous size, by their towering freeboard (4 - 5 m) and, most importantly, by the long-wavelength rolls that are so characteristic of the ice shelves. Jeffries[11] gives a review of the islands that have been discovered. Five islands (T-1 to T-5) were found[12] between 1946 and 1950. The Americans used Ice Island T-3 as a platform for scientific experiments for several years before it grounded and broke up in 1961. A large piece of T-3 remained in the Arctic Ocean, circulating around the basin until 1984. In the early 1960's, sixteen islands broke off from the Ward Hunt Ice

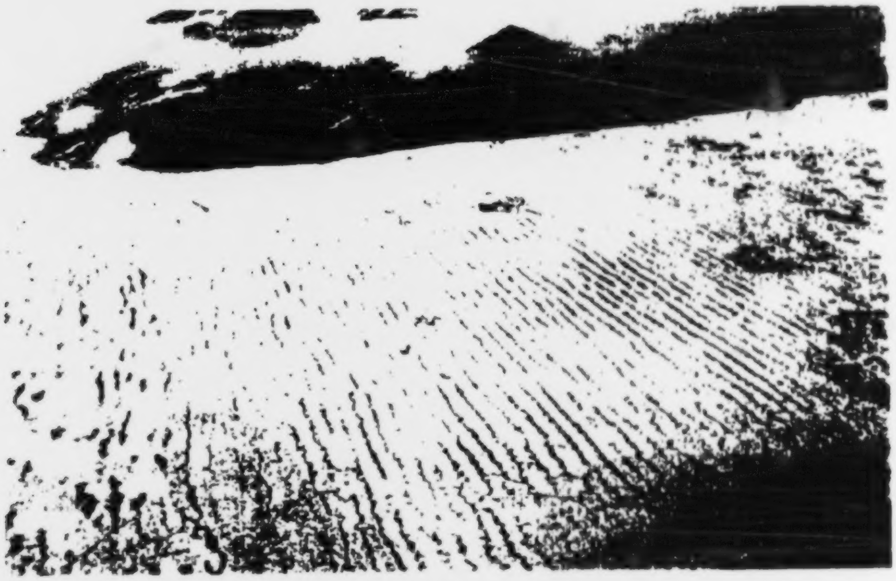

FIGURE 9. Regular rolls in Doidge Bay showing water-filled troughs. The camera is looking eastward the far shoreline runs roughly north-south

Shelf[13], and in 1982-83 at least eight new ice islands were calved from the eastern portion of the Ward Hunt Ice Shelf[14]. The largest was named Hobson's Ice Island (or Hobson's Choice by the more irreverent) after George Hobson, the Director of the Polar Continental Shelf Project. Canadian scientists occupied it for several summers. In 1986, the total number of ice islands was 32 to 34 (Jeffries[11]).

To the average person, imbued with stories of the Titanic and the dangers of the North Atlantic, the iceberg is perhaps the best known ice feature in the sea. 'Everyone' knows that the icebergs drift down from the Arctic, but most people, if they have ever thought about it, are pretty uncertain as to just where the icebergs originate and where they go. From the various comments I get, it appears that many southerners believe that the Arctic Ocean is chock-a-block with 'bergs. The truth is that, if one excludes the ice islands, there are no icebergs in the Arctic Ocean.

Icebergs are not made of sea ice, nor are they born in the ocean. Rather, they are composed entirely of fresh ice that has formed perhaps hundreds of miles from the ocean. In high arctic country, such as central Greenland, more snow accumulates in the winter than melts in the summer. The snow eventually builds to a thickness where its own weight compresses and transforms the underlying snow into ice. Large areas of thick ice and snow, such as are found on much of Greenland, are called ice caps. Once the ice grows thick enough (100 m, or so) the internal forces become so large that the ice will flow plastically. It flows downhill, albeit slowly, in thick rivers of ice toward the sea. These rivers of ice, or glaciers, eventually arrive at the ocean where large chunks (icebergs) break off (or calve). If the glacier is not afloat in the ocean, the icebergs will break off at the shoreline and will be relatively small. On the other hand, if the glacier extends out onto the ocean as a floating tongue of ice, the icebergs will be larger, with their length being several times their thickness. Small icebergs - up to 1,000 tonnes - are called growlers. Icebergs up to 10,000 tonnes are called bergy bits, and icebergs up to 100,000 tonnes are called small bergs.

Almost all icebergs found in the Arctic are calved from the glaciers flowing down from Greenland. According to the literature[15] some 10,000 to 30,000 icebergs are calved from the Greenland icecap every year, and the vast majority of these calve from the west coast. There are a few small glaciers on the east coast of Ellesmere Island contributing to the population, but most come from Greenland. The icebergs drift generally southward, although the average 'berg' may spend two or three years in Baffin Bay before it escapes into the Atlantic Ocean and melts. The steady current from the north prevents them from floating northward into the Arctic Ocean.

At DREP we were seldom concerned about icebergs since we worked in areas where they are rare. Icebergs do drift into Jones Sound (Figure 10) through Glacier Strait (between Ellesmere Island and Coburg Island at the eastern mouth of Jones Sound), but most of them return directly to Baffin Bay through Lady Ann Strait (south of Coburg Island). The occasional iceberg carries on westward along the north coast of Jones Sound and may spend a year or more there before being carried out by the easterly drift of the ice. They are rare enough that the occasional iceberg is a tourist attraction, but they are frequent enough to cause us to worry about the longevity of under-sea cables.

In Barrow Strait the situation is similar, with icebergs being seen only occasionally. Now and again an iceberg will come in from Baffin Bay and work its way westward along the north coast. Occasionally, too, an iceberg will come down Wellington Channel, which is east of Devon Island (Figure 10), having been calved from one of the small glaciers farther north.

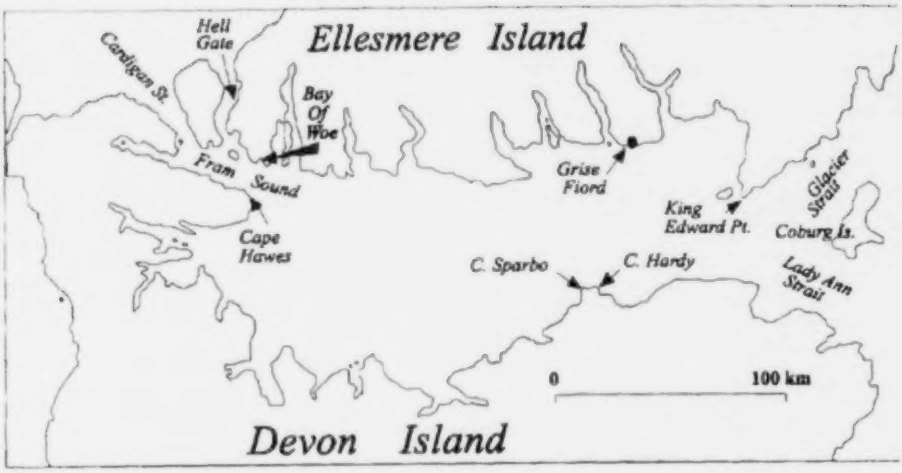
Ellesmere Island
Hell Gate
Cardigan St.
Bay Of Woe
Fram Sound
Cape Hawes
Grise Fiord
King Edward Pt.
Glacier Strait
Coburg Is.
C. Sparbo
C. Hardy
Lady Ann Strait
0
100 km
Devon Island

FIGURE 10. Map of Jones Sound. Icebergs travel down Glacier St. and Lady Ann St., but seldom move farther west into Jones Sound. Personnel from DREP have worked at Cape Hawes, Bay of Woe and Grise Fiord.

4.0 Transportation

4.1 Getting to the Arctic

Getting to the Arctic is difficult and expensive. The distances are large, and the population is sparse, which means that the number of commercial routes and flights is small. Competition is virtually non-existent. Canadian Airlines (now Air Canada) runs regular flights from the south to Cambridge Bay, Resolute Bay, Iqaluit (Frobisher Bay) and Nanisivik. Other northern communities, such as Grise Fiord and the weather stations at Mould Bay and Eureka, are served by commercial Twin Otter from Iqaluit and Resolute Bay on a not-too-frequent schedule. Canadian Forces Station (CFS) Alert, on the north coast of Ellesmere Island, is a military station, and it is served by a weekly military CC 130 (Hercules) flight, known as the 'Rotator', from Trenton, Ontario (See Figure 11). Nearly everyone arriving at Alert comes by Hercules.

During the short summer season ships can get into all these locations except Alert, and freighters bring in bulk freight such as fuel, building materials and large equipment. However, it should be noted by anyone who wishes to take advantage of ocean transportation that planning for such shipments must begin about a year ahead of delivery.

CFS Alert is a special case since Robeson Channel never opens up sufficiently for a freighter to get safely through to Alert. Consequently, Alert's fuel and other bulk supplies

FIGURE 11 A Hercules slowing down after landing.

are ocean-freighted into Thule, Greenland, and are transported by military Hercules over the relatively short hop (680 km) from Thule to Alert. This air haulage takes place two or three times per year, and the operations, which are called 'Boxtop', involve several 'Hercs' all flying 24 hours per day for a frenetic two weeks or so.

The Arctic Acoustics Group at DREP has had relatively easy access to the Arctic because of its association with the Canadian military. Every year Air Command has supplied several Hercules aircraft for transporting DREP equipment and people to the Arctic and back. The only constraint as to destination has been the requirement for a runway long enough (about 5000 ft. or 1500 m) for the aircraft. This eliminated Grise Fiord as a landing site, but it included every other settlement of a respectable size.

It should be noted in passing that Hercules aircraft can be equipped with skis so that they can land on snow or ice. To the best of my knowledge the Canadian military have never flown ski-equipped Hercules; they certainly have never been requested to do so by us. However, the Americans have regularly used ski-equipped Hercules to land on the ice in Independence Fiord in northeastern Greenland for the purpose of establishing an ice camp. The Americans do, of course, prepare a landing strip on the Fiord beforehand, and they must ensure that the sea ice is adequately thick.

DREP has always used wheel-equipped Hercules, which have taken them and their equipment to one of the land-based strips in the Arctic. Our typical freight load has been in the ballpark of 30,000 lb. With this load the Hercules can get comfortably from Victoria to Resolute Bay without refuelling, but not much farther. A flight to Alert requires a stop for fuel at either Yellowknife, Cambridge Bay or Resolute Bay.

Hercules aircraft have also delivered fuel and other bulk freight to us out on the pack ice. They have dropped such loads by parachute or by 'Low-Altitude Parachute Extraction System' (LAPES). (See Figure 12.)

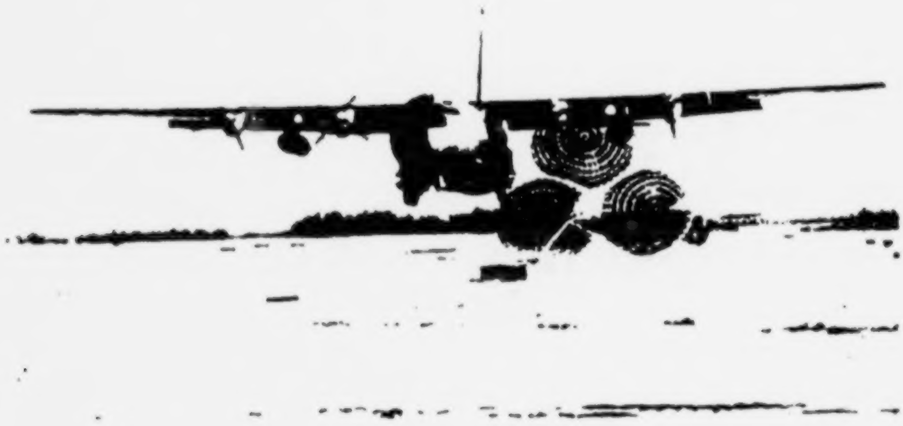

FIGURE 12. A Canadian Military CC-130 (Hercules) dropping freight at a remote site with its Low-Altitude Parachute Extraction System (LAPES). The parachutes jerk the freight out of the aircraft's large rear exit hatch. DREP has had a number of such drops in the Arctic. Recently, however, Canadian authorities have declared this manoeuvre to be too dangerous, and it is no longer used.

4.2 Travelling within the Arctic - 'Off-Strip'

4.2.1 The Aircraft

Once the Hercs have dropped off the people and equipment, smaller aircraft must take over the job of transporting them to the more inaccessible sites such as the sea ice. The small-aircraft workhorse of the Arctic is the DeHavilland DHC-6 or Twin Otter (Figure 13). It is one of the world's best Short-Take-Off-and-Landing (STOL) aircraft, and its runway requirements are minimal. The pilots would like a landing strip out on the ice to be about 360 m (1200 ft) long, but they will accept less if good ice is not available. Their propellers can provide a lot of reverse thrust and can stop the airplane very quickly. I have been in a lightly loaded Otter that came to a stop on rough ground in only about 36 m (120 ft) As is indicated by the name, the Twin Otter has two (turbine) engines and two propellers. The dual engines give it an element of safety, especially when flying over open water, that was not available to its single-engine cousins, the Beaver and the Single Otter.

FIGURE 13. A commercial CC-138 (DHC-6 Twin Otter) landing 'off strip' Since the late 1960's DREP has made extensive use of both the civilian and military version of these aircraft in the establishment of its remote camps.

The Twin Otter will carry a freight load of about 1800 kg (4000 lb) if the flight is short and it does not have to top up with fuel. A load of 1400 kg (3000 lb) is, however, much more typical. The load also depends on the roughness of the landing site since a rough site has the potential of damaging a heavily loaded aircraft.

The Twin Otters are usually fitted out with wheel-skis in the spring and with 'Tundra tires' in the summer. The wheel-ski combination allows the aircraft to take off and land with either wheels or skis. Each ski has a slot in it large enough to allow the wheel to pass through. When the Otter is to take off from or land on a gravel or asphalt strip, the skis are raised (by hydraulic cylinders) so that the aircraft is sitting on the wheels. When it is to land on snow or ice the skis are lowered below the level of the wheels. We regularly use this wheel-ski combination because one end of our flights is often at a prepared runway and the other end is on the snow or ice. Skis without wheels are available, and since they are lighter than the wheel-ski combination they allow the aircraft to carry a somewhat greater payload. However, they have the disadvantage that they can not be used on a bare runway, and they can suffer damage when they are used on a strip where the gravel shows through the packed snow.

In the summer, after the snow has gone, the skis are removed. When the aircraft is to be subjected to rough off-strip landings, it is equipped with 'Tundra tires', which is the accepted name for partially inflated oversized tires. These large mushy tires provide a soft cushion to what otherwise might be a dangerously rough landing. According to northern legend, this idea was first used by Weldy Phipps, an early bush pilot who flew small aircraft out of Resolute Bay. He put DC3 wheels on small aircraft such as Single Otters and kept the tires only slightly inflated. The disadvantages to the Tundra tires are their extra weight, which slightly decreases the freight that can be carried, and their extra air drag, which decreases the airplane's air speed. The aircraft in Figure 13 is fitted with over-sized tires.

The Twin Otter can also be equipped with floats for working off the water in summer. This attachment, however, is not common in the Arctic where lakes are not plentiful and the sea usually contains ice even at the best of times. Floatplanes are usually used farther south in lake country.

Helicopters of various kinds constitute the other main means of medium-distance transportation in the Arctic. The Bell 206 is relatively small and does not have a large freight-carrying capacity. It is good for reconnaissances and for small jobs on the ice, and it is less expensive to charter than the larger Bell 212, or Twin Huey, as it is called. The Twin Huey (Figures 14 and 15) is a much larger aircraft, and will carry a freight load of 1400 kg (3000 lb) if the fuel load can be kept to a minimum. The word 'Twin' here refers to the fact that it has two turbine engines both powering the same drive train. Having two engines is again a safety feature since the helicopter will fly with only one engine operating, albeit with a reduced load. Several of us at DREP have reason to be thankful for this feature since at various times the 212 has had an engine flare-out or has had one of the engines refuse to start when we were miles from a warm building.

A question that is sometimes asked is, "Which is better for Arctic work, a fixed-wing aircraft or a helicopter?" Of course the answer is, "It depends." The following discusses the relative advantages and disadvantages of the Twin Otter and the Bell 212.

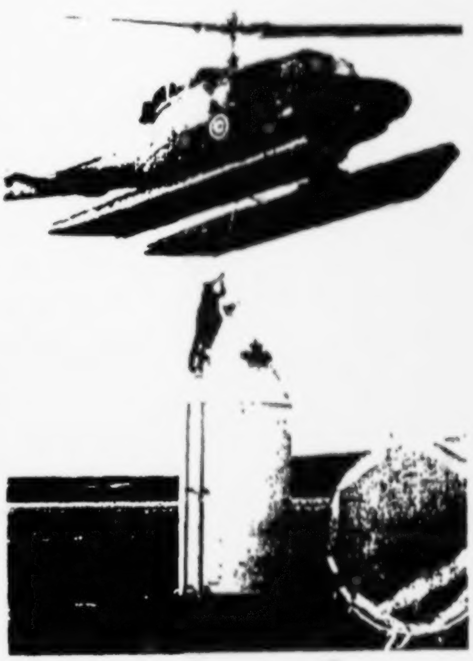

FIGURE 14. A Bell 212 preparing to sling a 'silo', which is a weatherproof container for parabolic antennas, radio equipment and batteries.

If there are prepared landing strips at both ends of the flight, the fixed-wing aircraft is by far the better freight carrier. It is faster (180 knots vs. 100 kt), it has a greater range (roughly 700 nautical miles round-trip vs. 250 nm), and it can carry a slightly heavier payload and appreciably more volume. If, on the other hand, there is no useable strip at the remote end of the trip (for example, on rough ice or on a hilltop), the helicopter is the only aircraft that can do the job. Sometimes, too, the only way to carry a large, heavy or awkward piece of equipment is to sling it below the helicopter. We have used the Bell 212 to sling generators, steel I-beams, small buildings, heavy tent frameworks, and barrels of fuel. We have used it to help erect and take down towers, to lift large chunks of ice out of an ice hole and to lay cable across the countryside. For some purposes, the helicopter has no substitute.

Both types of aircraft can be used for reconnaissance purposes. The Twin Otter is better if a large area is to be examined from the air and if there is no requirement to land at a specific spot. If we wish to land a Twin Otter on the ice to set up an ice camp, for example, we must be prepared to be flexible as to the exact landing spot. In the Arctic Ocean, where the ice is rough, it is quite usual to search an area of sea ice from five to ten miles square. If we wish to go to a particular spot on the ice we must use the helicopter.

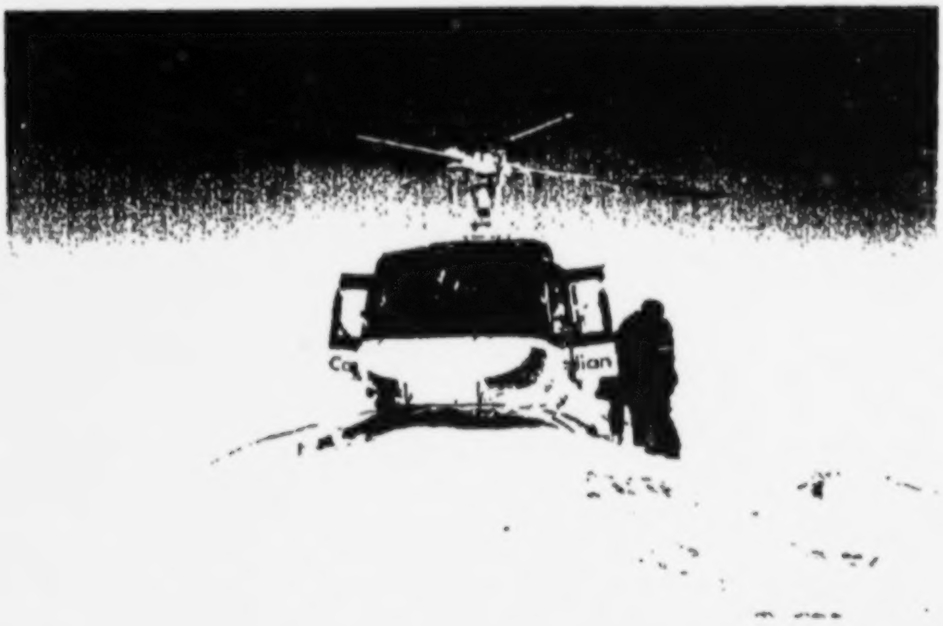

FIGURE 15. A commercial Bell 212 Twin Huey straddling the narrow top of a 600-m (2000-ft) peak. It has placed us there so that we can install a radio repeater.

Some operations, because of their size and complexity, require both a fixed-wing aircraft and a helicopter. There is a further advantage in having two such aircraft in the area, since either aircraft is capable of assisting the other in an emergency.

4.2.2 Landing on Ice - Finding A Strip

Working on the ice requires the establishment of a camp, and the first step toward this is finding a landing strip on the ice for a fixed-wing aircraft, presumably a Twin Otter. This is a shared responsibility between the Chief Scientist and the Otter pilot. Before the flight, the scientist will specify the area where he wishes to set up a camp, and he will discuss any constraints or preferences he might have. For example, he might be happy with anything within a 10-mile-square tract of ice. On the other hand, if he must recover something mounted on the bottom, he might need to be very close to a specific geographic location.

It is the pilot's responsibility to land at a safe location. The ice must be thick enough to support the aircraft with a reasonable margin of safety, and the surface must be smooth enough that the aircraft is not damaged on landing or on taking off. This roughness constraint is a grey area, since the pilot requires a much smoother surface if the aircraft is heavily loaded than if it is empty. Usually the aircraft will be quite light on the first trip out. Once a strip is found, the pilot will gauge how much freight he can carry based on the roughness of the landing. Over the next week or so, the scientific crew will spend a substantial amount of time smoothing and grooming the landing strip, especially for the 'back-haul', which requires a longer runway than the establishment of the camp.

Finding a new location and landing on it is an anxious time for a pilot. After all, his aircraft and several lives are on the line. Thus it is wise to treat him with particular tact when a landing spot is being sought. If you see a possible landing spot, you might suggest it, but remember that he has probably seen it, too, so be discrete. On the other hand, the scientist is the customer, and the pilot will do his best to oblige. He will often indicate that he welcomes extra pairs of eyes. From his point of view, all that circling around is chargeable time. Remember, he is the ultimate judge as to whether or not a spot is safe. When he does find a patch of ice that he is willing to try, he will always check that the customer is happy with it.

The types of ice that are candidates for a landing strip have been mentioned before. In the channels through the Arctic Islands, much of the ice is first-year or annual ice. The ice under the snow cover is generally quite smooth except where the ice is ridged, but the landing surface may well be very rough because of hard packed snow drifts. If there have been bad storms since the ice formed, the pilot may have to look long and hard to find a suitable spot. Remember that the surface looks much smoother from an altitude of several hundred feet than it really is, so contain your critical impatience and trust the pilot.

In areas such as the Arctic Ocean, where most of the ice is old, the problem of finding a landing strip is more difficult. Most of the ice is multi-year, and even the smoother areas are quite rolling - the result of years of melting and refreezing. Refrozen leads, Figure 16, for example, which are long narrow strips of ice between the large floes, are possible landing sites. They are smooth and easily spotted from the air.

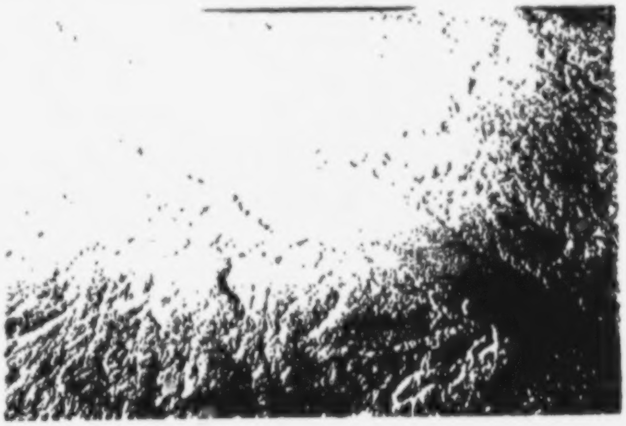

FIGURE 16. A refrozen lead surrounded by heavier ice. This would probably make a good landing strip

The relevant concerns are: is the lead long enough and is it thick enough? The length can be estimated by a measurement of the time it takes to fly along its useable section. The thickness is estimated by the look of the ice both on the lead and in its vicinity. New ice that has not been covered by snow has a recognizable appearance. If it is black or grey in colour, it is doubtless too thin (Figure 17). If it has visible ice crystals standing up from its surface it is probably less than about six inches thick. If there are no snowdrifts on it, then the lead has formed since the last blow. If, on the other hand, the whole area looks stable and there are no new leads, then probably the one you are looking at is reasonably old and thick (Figure 18).

Most ice in the Arctic Ocean is several years old and very thick. However, most of this is far too rough for an aircraft to land on. If, however, a smooth patch of old ice can be found, it will make a good landing strip - better, in fact, than a refrozen lead since it will have greater resistance to being crushed by pressure. A refrozen melt pool on top of an old floe is a good candidate since the new sheet of ice will be level and smooth, and the ice under it will be old and thick. As mentioned before, these pools are not abundant since the summer's melt water usually runs into the ocean through cracks in the old ice. However, they are worth watching for. Another possible candidate is two-year ice or other ice that is not yet old enough to have developed the full ablation rolls and hummocks. If this ice is cushioned by new snow it can make a reasonably smooth landing strip. The pilot will, of course, be on the watch for chunks of ice or steps in the ice that are just covered by snow. These hidden land mines can do serious damage to a ski.

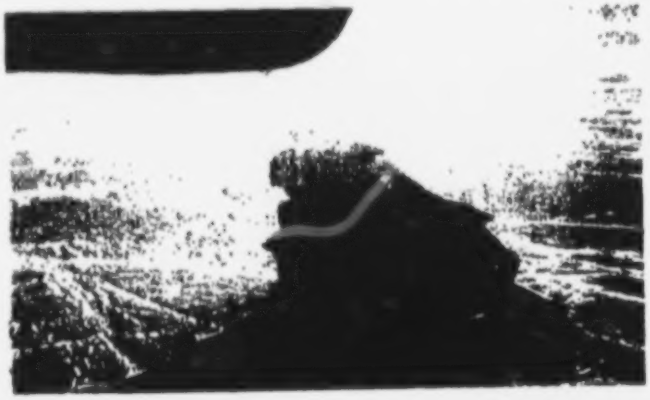

FIGURE 17. A lead that is only a few days old. Its darker colour and lack of snow tell the tale The ice on the right of the lead is thicker than that in the centre There may be open water along the left-hand edge This is not a landing strip

The minimum ice thickness for a safe landing on sea ice is about 45 cm (1.5 ft). The military specifications for minimum ice thickness are given in a report[16] by Air Transport Group, Trenton. They make the point that the warmer the average air temperature, the thicker the ice must be. For the coldest temperature quoted in the report, 14° F (-10° C), the thinnest allowable sea ice for a Twin Otter on regular operations (as opposed to emergency operations) is 40 cm (15.5 in). This assumes that the ice is not cracked or flawed in any way. In practice, the pilots with whom we have flown have required the ice to be at least 60 cm (24 in) even though the average air temperature was much colder than -10° C. Thus, their safety margin was more than adequate. As a matter of interest, the same report quotes a minimum thickness of 115 cm (45 in) for a Hercules on skis.

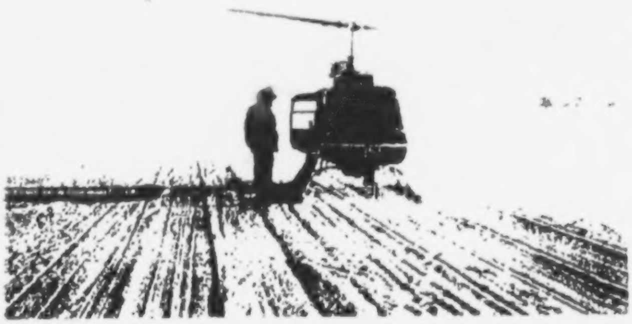

FIGURE 18. This shows the very smooth ice of a refrozen lead The tracks were made by a Twin Otter, not by the Bell 206 helicopter in the picture Note the rough ice bounding the lead

The question still remains as to how the pilot knows the ice is thick enough when he lands on it. The only ice in question is annual ice; anything older than this is much thicker than the required minimum. New sea ice is quite salty (about 5 parts per thousand), and it is important to note that this salinity makes it behave quite differently than fresh ice (lake or river ice). Sea ice is not as strong as fresh ice, but more importantly here, it is much more flexible; it bends a lot before it cracks. This means than when a Twin Otter sets down on thin sea ice the ice will bend like a rubber sheet, but it probably will not crack immediately since it takes time for the ice to bend enough to break. Thus, the experienced pilots look for travelling waves in the ice rather than for wet snow. Sometimes they will maintain a fairly high speed and taxi around the lead until they are sure that the ice is not bending under the weight of the aircraft.

The military Twin Otter pilots, on the other hand, have set procedures that seem to have been designed for landing on lake ice. They do a series of touch-and-goes on the ice, each time slowing down a little bit more before take-off. After each landing they look to see if the snow shows any sign of wetness. This would make sense if the ice were brittle, but thin sea ice will just bend out of the way. The touch-and-goes do no harm - they just waste time - and one can, of course, look for travelling waves during the touchdowns. But I, for one, would feel a little more secure if they kept moving for a while and did not stop so abruptly after the final touchdown.

If there is any doubt as to the thickness of the ice, a hole is drilled in order to measure its thickness, and this is done before the engines are shut down. Once the drill stem is into the ice two feet, or so, the anxious time is over, and the pilots will start to throttle down.

4.2.3 Grooming Ice Runways

Once a landing strip has been chosen and the aircraft has landed for the first time, the pilot usually walks the area looking for bad bumps - particularly hummocks that are made of ice rather than snow. If the area is fairly rough he will pick the smoothest route he can find, and he will mark off the strip with black garbage bags filled with snow, putting a line of bags on both sides of his 'runway'. He will point out any particularly bad lumps that he would like levelled, and then he will leave for the first freight load.

Having a smooth strip enables the pilot to bring in larger loads without damaging the aircraft, and it is well worth our while getting out with shovels and picks and knocking the tops off the hard snow drifts. It is also worth while improving the strip for the back-haul. To take off with a heavy load a Twin Otter requires a substantially longer strip than it needs for landing with the same load. The strategy, then, is to concentrate initially on making a short but smooth strip, and later to extend the length of the strip in anticipation of the back-haul.

Over the years we developed a number of drag tools for levelling out the snow on the landing strips. Figure 19 shows one model. It was simple and reasonably effective, although it suffered from a fault common to all such drag tools - it smoothed out the high-frequency bumps, but it did not level the long-wavelength rolls, and it is the long-wavelength rolls that can shake and damage the wings of the Twin Otter.

Nonetheless, with a combination of pick, shovel and drag tool it is possible to make quite a smooth runway. The dragging has the added advantage that it stirs up the snow, and once stirred up it will set quite hard in a day or so.

Once started with the drag tool, however, most people find it hard to stop. They tend to become very fussy, and they continue work on a runway long after they have ceased making any substantial improvement. This condition is known as 'runway fever'. It is fairly harmless.

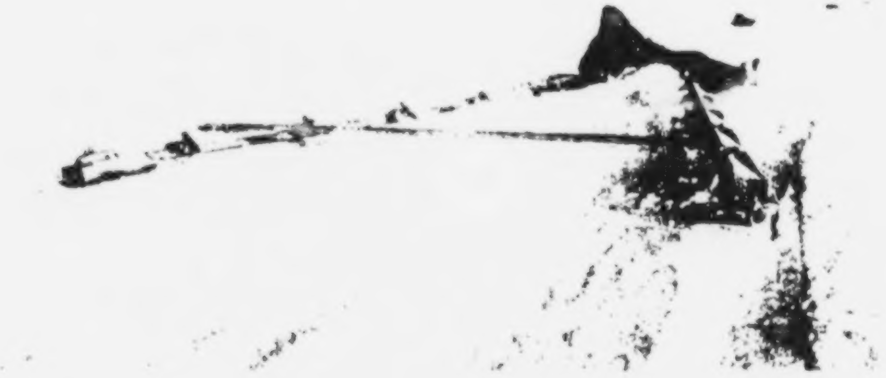

FIGURE 19. A drag tool being used to level and harden a landing strip on the Arctic Ocean. It is being pulled by a large skidoo behind and to the left of the camera. A weight on the back was needed to make the drag tool pick up snow from the hummocks. An 'intelligent' weight (as above) can cause the snow to be dropped where it is needed. Note the garbage bags marking the edge of the strip.

4.3 Transportation on the Ice

4.3.1 Snowmobiles

The first level of transportation is to get to the Arctic, and the second is to get to the research area, whether it be on land or ice. Once there, the vehicle of choice for moving freight or people over short distance is the snowmobile. A small snowmobile and sled can move a lot of freight quickly, especially when compared to what can be done by a man-hauled sled.

Most of our snowmobiles have been made by Bombardier, and their generic name for a snowmobile is 'skidoo'. The 'Elan', a particular model of skidoo, has been a most popular choice of skidoo at camps out on the Arctic ice. This is primarily because it is small and light and can be loaded onto a Twin Otter without straining our backs or barking our knuckles. Also, the Elan is easier to start in very cold weather than are the bigger machines simply because the smaller engine turns over more easily - the big two-cylinder machines needing a powerful person to pull-start them at -40°. The Elans have the further advantage that they are light enough for a person to haul them around should they get stuck in the snow. The larger machines require at least two people to manhandle them in this way. Unfortunately, the Elans are no longer being procuced, and we are looking various other small snow-mobiles.

The big skidoos, however, have their advantages. They are more comfortable, and they are safer than the small ones at higher speeds. Also, they will pull heavier loads. The airstrip drag tool, in particular, needs a large skidoo to pull it. Our choice for the very heavy pull has been a Nordic (Bombardier), but it gives a rough ride, and it is a heavy brute to get into a Twin Otter. We have used various versions of the Skandic (again Bombardier) as a mid-sized machine, which will give a smooth comfortable ride and will pull a reasonable load. The Skandic was very popular at Alert when our ice camp was just offshore, 6 km away from the town.

A few words about operating skidoos in cold-weather might be in order. The Elan, in particular, starts remarkably easily at very cold temperatures. As mentioned above, this is partly because the engine is fairly small and can be pull-started by a person of average strength. Another reason that it starts easily is that it has a manually operated fuel pump that injects raw gasoline into the air stream just past the carburettor. This gives a very rich gasoline mixture, which is necessary for starting an engine at extremely low temperatures. The fuel injector is much more effective than a choke at these temperatures. The Elans characteristically start on the second or third pull even at -40° and even after being unused for ten months.

The main rubber track on which the skidoo rides loses its flexibility in the extreme cold. At temperatures below about -25° C a track that has not been exercised for several hours is like a belt of iron; it just refuses to turn. Starting the Elan's track at -40° usually requires two people, one to tip the skidoo onto its side and rev up the engine, and the other to pull on the track in order to help the engine. This process is quite hard on the main V-belt that connects the engine to the transmission. It slips on the pulleys and smokes quite badly during these cold-weather start-ups. This burning process reduces the V-belt's width and, thus, its working life. The smoke from the belt and the exhaust from the roaring engine blanket the operators and sometimes hide them completely. It is a scene that Dante would appreciate, even though the temperature is all wrong.

The larger skidoos are too big for a helper to provide significant aid by pulling on the track. Thus, the V-belt has to do all the work of freeing it up. However, most of the large skidoos have the advantage of having a reverse gear, and the operator can rock the skidoo backward and forward to loosen the stiff track. Finally, it should be evident that a cold skidoo should be exercised and warmed up before it is hitched to any substantial load.

The spares kit carried by every skidoo should include a main V-belt since the one in use will slowly wear thinner and will eventually not turn the transmission. Operators should be shown how to change the belt. Another necessity for the spares kit is a spark plug or two. Sometimes, when a skidoo is running roughly or refusing to start, the problem is simply a bad plug (or plugs in the larger machines). Amazingly, the old one often exhibits no sign of fouling or damage even though it is the culprit. On the other hand, the plug is sometimes burnt to the point where the gap is two or three times as large as it should be. A burnt plug should be suspected if the snow-mobile is producing only a fraction of its rated power.

Whether or not the spark plug is actually the problem, it is usually changed since a new one costs so little. The spares kit should also include enough tools to change the V-belt and the spark plug. Other repairs, such as replacing a broken Bogie assembly or a broken ski spring can usually be done back at a warm camp.

Because of the great number of ways a skidoo can fail, and because of the finite probability of injury, a good operating rule is never to go on a long skidoo trip alone. A second skidoo could possibly eliminate a very long walk, and, if an injury were involved, it could even save a life.

4.3.2 Sleds

A sled is a necessary adjunct to a skidoo if equipment is to be moved from place to place. Consequently, we have always been interested in the various types of sled. We started with a basic Inuit komatic, but over the years our sleds evolved to a model that was more suited to our uses.

A komatic is a long, fairly narrow sled consisting of a pair of runners with a deck lashed to it. The runners in a modern komatic are made from 2 x 8 or 2 x 10 lumber placed on edge and cut so that the runner curves upward at the front. The 2-inch bottom of the runners are often shod with a strapping of cold-rolled steel, which provides extra strength as well as abrasion resistance and lowered friction. The deck may be made from plywood or from individual boards (1 x 6's or 2 x 4's, for example). To attach the deck, the runners are drilled with a series of holes in the appropriate places so that the deck planks can be lashed down with rope. Lashing is a much more resilient means of fastening than either screws or nails; it allows the sled to 'work' in torsion as it runs over the rough snow. The various joints share the load, and this decreases the maximum stress and, therefore, the likelihood of a break. If the lashing gets a little loose, it is easy to retighten. The komatic is attached to a skidoo by a simple bridle made of rope or of wire rope. This type of sled is rugged, simple to make and easy to repair on the trail. We used them for several years.

However, the komatics have a number of features we did not like. They were heavy (because of the solid runners), and the runners were narrow, which caused the sled to sink into soft snow. Our original komatics were copies of the ones used by the Ice Research Group (originally at DREO but later at DREP) who favoured narrow sleds for long-distance travel through rough ice. However, we found them to be too small and too unstable for our purposes, and we made them wider. Another unpleasant feature was the pounding of the komatics as it travelled over hard snowdrifts. The front of the sled would angle up over a sharp snow ridge until the sled was about half-way over, and then it would crash forward onto its nose. This steady jarring was hard on people and equipment. A solution to this problem came much later.

The flexible bridle, too, gave trouble, and was actually the cause of several injuries. The accidents usually happened during whiteout conditions when the driver could not distinguish rough snow or ice features against the background whiteness. He would hit an invisible snow drift and be flipped off the skidoo into the path of the following komatic. Even if the skidoo had turned over and had stopped, the sled might well hit him since the wire-rope hitch provides no braking action. This scenario was a cause of one medical evacuation and several more sore backs.

The final reason why we stopped using komatics was that we found a commercial sled manufacturer (Custom Sleds of Radisson, Saskatchewan) who was making sleds that were very close to what we wanted and who would make alterations according to our wishes. Figure 20 shows a komatic together with our first new sled design.

The runners of the new sleds were curved oak boards 4 to 5 inches wide, the larger footprint providing much more support in soft snow. The decks were made of plywood with oak reinforcement, and they were supported on steel brackets about 8 inches above the runners. The flexible bridle was abandoned as a pulling harness. Instead, the sled was attached to the skidoo by a rigid triangle-shaped framework which was free to pivot only up and down (Figure 20). Now, when the skidoo tipped over and stopped, the sled stopped, too. Although the drawbar framework worked well, we had some teething problems with the way it was connected to the skidoo. After fighting for a year or so with hitch pins and various means of keeping the pins from falling out, we switched to ball-and-socket trailer hitches. We found them to be both secure and quick to hook up, and we never went back to bolts or pins.

The runners were clad with ultra high molecular weight (UHMW) polyethylene, which cut the friction and made the sleds easy to pull. However, on hard snow the first sleds tracked

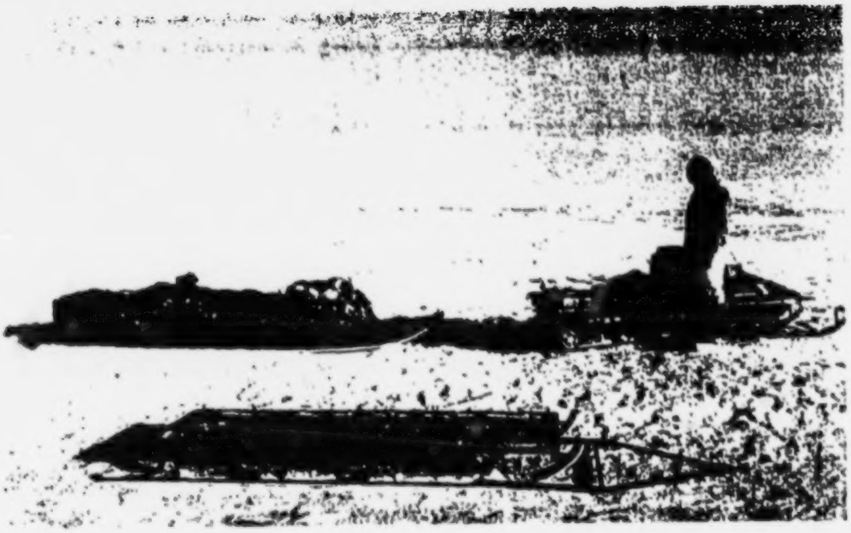

FIGURE 20. Komatic (with solid hitch) in the background, and our newer-style sled in the foreground. The komatic belonged to the Parks Branch.

very poorly, the slick runners sliding every which way. We cured this behaviour by putting a narrow groove down the centre of the polyethylene runner. Later, we found that the abrasive conditions of late spring work on land (when the dirt started to show through the snow) was very hard on the polyethylene runners, especially the front few feet which seemed to take most of the punishment. Here, the half-inch-thick polyethylene wore completely away, whereas, interestingly enough, the after section of the runner wore very little. To combat the wear, we clad the front third of the runner with steel strapping.

Our first commercial sleds pounded on rough snow and ice just as badly as did the komatics. They were equally rigid since the oak-plank runners in combination with the deck formed a very stiff beam. To cure the pounding problem, we designed a sled framework that was more flexible. The stiff triangular webbing of steel brackets holding the deck to the runners was replaced with vertical posts that had only side-to-side rigidity. In the fore-and-aft direction the supports were built to be flexible; in fact, bushings were installed so that the stand-offs could easily rotate about a horizontal axis at both its bottom and top. Thus, there was no triangulation to take the shear and make the 'beam' stiff. Only at the front, where the runner curved up, was there a hard connection between the deck and the runner. In other words, there was only one triangle on each side of the sled that prevented the deck from flopping down onto the runners. As a result, the runners and the deck flexed independently and no longer worked together to form a stiff beam.

This flexibility made a tremendous difference in the smoothness of the ride. The sleds snaked over the bumps instead of pounding on them. No longer did people shudder at the idea of riding a sled, and no longer did car batteries arrive at the end of a long ride broken and leaking. Figure 21 shows a loaded sled conforming to the rolls in the snow. This ability to conform to the undulations did make the sled slightly harder to turn - its only disadvantage.

FIGURE 21. A flexible sled straddling a low spot. A definite bend in the sled runners can be seen The garbage bags in the background mark a landing strip

We were concerned at first that the new design might not be strong enough, considering that the runners were continually flexing and were sometimes quite seriously stressed, but those fears were soon set to rest. The sleds carried heavy loads for many miles over very rough terrain, and in several years of operation only one runner broke (out of many sleds). And that happened because of a poorly selected oak plank in which the grain 'ran out'. In other words, the wood grain did not run parallel to the plank but at an angle to it, thus encouraging the wood to split. The manufacturer apologized and replaced the runner without charge.

We experimented briefly with toboggans for carrying fuel drums (Figure 22). They are so low to the ground that the drum can be rolled right onto it. In spite of this advantage, the toboggan was never very popular; it was just not as versatile as the sleds.

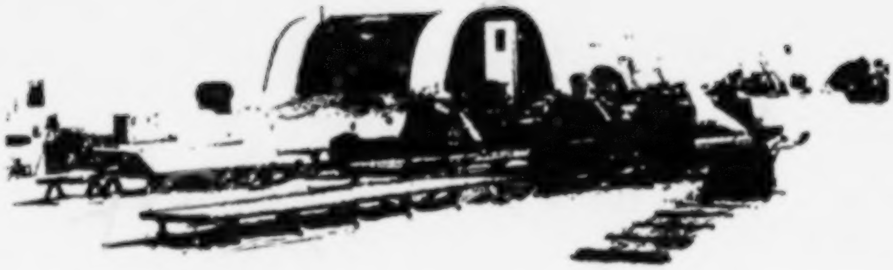

FIGURE 22. The toboggan in the foreground can carry five barrels of fuel (2000 lb) To its left is a flexi-sled, and beyond that is a rigid sled

4.3.3 Miscellaneous Vehicles

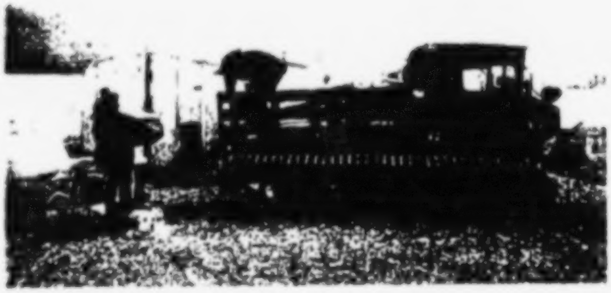

FIGURE 23. The Thiokol was used in the Barrow Strait region during the 1970's.

At various times we have required larger vehicles than ski-doos. In the '70s we used tracked Thiokol vehicles (Figure 23). More recently we purchased a Track-Truck (Figure 24) and two Posi-Tracks (Figure 25), both made by ASV of Grand Rapids, Minnesota. The Track Truck is an all-terrain vehicle having a two-person cab and a small covered (and heated) freight carrier in the rear. Although this performs very well in the snow, it was bought more for cross-country use during the summer when the snow is thin to non-existent.

The Posi-Track is a small tracked fork-lift vehicle that we found to be extremely useful. We use it to load aircraft, to clear snow from building sites, to install Gantry cranes, to move freight and fuel, to remove ice plugs from melt holes and any other job that required lifting and moving. It has a lift limit of about 1600 lbs, so it will not handle the really big jobs, but for us it was perfect. The fact that we bought a second Posi-Track a year or so after the first one gives an idea of how much we liked it.

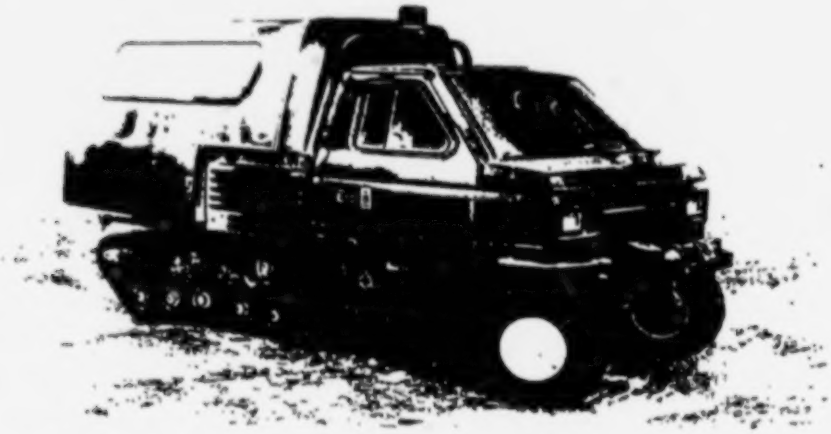

FIGURE 24. The Track Truck

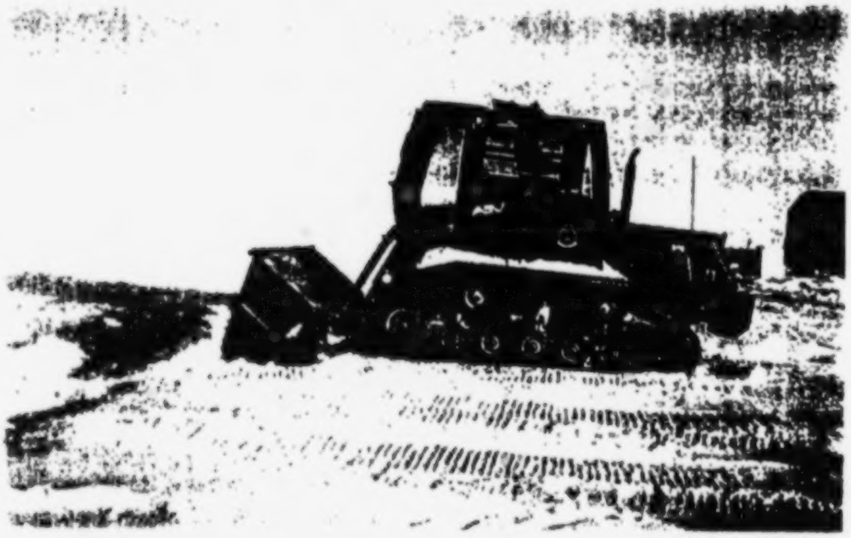

FIGURE 25. Posi-track with DREP built snow bucket. Colin Ganton, who designed and built the bucket, is shown here exercising it.

5.0 Living and Working in the Arctic

5.1 Coping with the Cold

5.1.1 The Problem

Cold has a deleterious effect on both people and equipment. Nothing ever gets done as fast as 'it should', and even the most experienced people tend to overestimate how much can be done in a day. This is partly because the equipment does not work as well in the cold as it does in the warm, and unexpected breakdowns put kinks in the time-line. Gasoline and diesel engines often won't start until they are brought inside and heated for an hour or so; seals fail; neoprene o-rings get hard; electrical insulation gets stiff, sometimes to the point of flaking right off the wire; 'flexible' fuel lines get so hard that they will snap if they are forced; most plastics get hard; all plastics shrink; batteries lose capacity; propane tanks have no pressure, and even the kerosene sometimes gels. One cannot even rely on steel; some steels get brittle in the very cold, and springs seem to break more often than they do down south.

In our experience, most of the serious breakdowns experienced by Twin Otters or helicopters happened when it was very cold. We have had a Twin Otter 'lose' an engine - it had to be replaced with a new one outside in the cold. And we have had one lose a windscreen - it cracked for no apparent reason. All hydraulic seals are a concern; the mechanics are always on the watch for the telltale red spots of hydraulic oil on the snow.

Once something fails it has to be fixed, and, if it cannot be brought into a warm workshop, the repair is usually slow and sometimes painful. Bare hands will start to freeze in about 15 seconds at -30° if there is a bit of a breeze. On the other hand, virtually nothing can be done with mitts on, so this leaves light gloves as the usual compromise.

All sorts of makeshift shelters and heaters have been rigged up when bare-hand work was required, and this took time. When the Twin Otter's engine had to be replaced, a teepee-shaped affair was built over the engine and part of the wing, and a Herman Nelson heater was used to heat the space, the engine and the mechanic (Figure 26). Although this provided adequate warmth, it did not give the mechanic enough ventilation. The wind was very changeable in direction, and it was hard to keep the Herman Nelson's exhaust away from the tent. The result was that the mechanic suffered a touch of carbon monoxide poisoning and was laid up for a day. This is the sort of unexpected delay that 'shouldn't happen' but that must be built into the timetable as a contingency.

5.1.2 Keeping Warm

5.1.2.1 Generalities

Probably the most important task in the Arctic is to keep oneself warm. Luckily this is not very difficult (except for the hands and face) since modern fabrics and insulation are light, warm and easily dried. However, there are a few basic things to remember. It is important that all clothes be loose so that circulation to the extremities is not impeded. An extra pair of socks, for example, will be counterproductive if they cut down the blood flow. Another general principle is that clothes must be dry to be warm. In very cold weather, boots, mitts and gloves should be looked after with an almost religious zeal. The layers should be taken apart and dried every night.

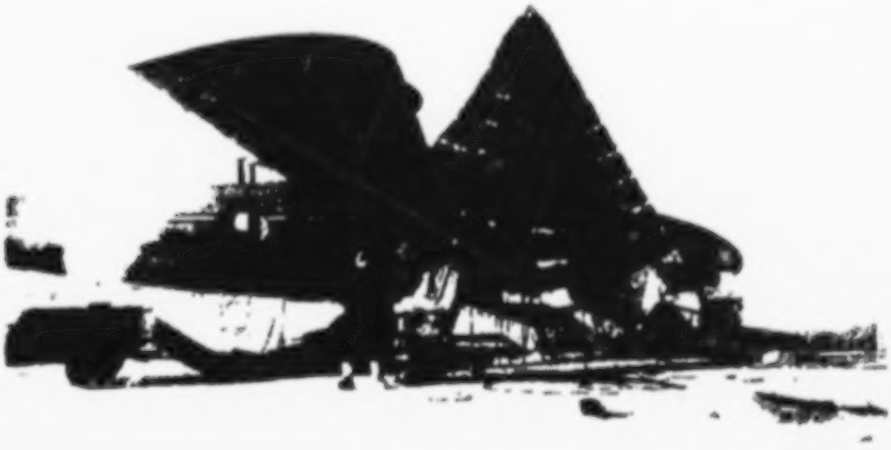

FIGURE 26. Replacing the Twin Otter's starboard engine in the bitter cold A tent made of a parachute gave the mechanic some protection from the wind. The 'Herman Nelson' (on the left) provided the heat.

Many people associate hypothermia with cold climates. It should, however, be associated with wet climates where the temperature is close to the freezing point (which, compared to arctic temperatures, is quite warm). Wet snow or rain will cause clothes to become wet, and wet clothes are not good insulators. Moreover, at these warmer temperatures, people tend to underdress. The net result may well be a serious loss of body heat. The situation is different in the cold, dry climate of the Arctic. People dress for the cold, and, because their clothes do not get wet from rain or wet snow (nor, hopefully, from perspiration), their core temperature stays normal. A greater concern at arctic temperatures is freezing one's extremities.

At the risk of insulting the average Canadian, the following summarizes our experience as it pertains to dressing for the cold. The subject divides naturally into 'feet', 'hands', 'head and face', and 'the rest', legs, arms, torso, etc.

5.1.2.2 Feet

We use the mukluks that are issued by the Canadian Military, and they are marvelously warm. With a little care we can work outside all day at -40° without being bothered by cold feet. The mukluks consist of a rubber-soled canvas boot enclosing a number of layers of thermal insulation. The boot extends most of the way up the calf, and a tie at the top of the canvas legging keeps the snow out. The layers of insulation are as follows. Closest to the skin are one's personal socks, either cotton, wool or polypropylene. Over this goes a thick felted wool duffle sock. The sock is actually doubled to give twice the insulation. A commercial version of the mukluks uses a single duffle, and we have been told by people wearing them that they are not warm enough. Next, a felted insole goes below the duffle sock. It is about 1 cm thick when new, but it soon gets squashed thinner. Finally, a nylon screen insole is placed under the felt insole to provide a small insulating air gap between the insole and the boot. Folklore has it that the moisture from the foot works its way down and freezes in this nylon mesh, and then at the end of the day you get rid of the moisture simply by knocking the frost out of the mesh. This is the theory, but it is not borne out in practice. What really happens is that some of the moisture does indeed work its way down into the cold region below the insole, but it freezes to the rubber of the boot. For the rest of the day one slides around on this sheet of ice. The mesh does, however, keep the insole from freezing to the boot, and the air gap does provide some insulation. If either the mesh or the insole has been forgotten, its absence is soon noticed.

More than any other item of clothing, the mukluks must be dried every night to keep them working well. Wet duffle socks are poor insulators, and if they are not dried they will not do their duty the following day. Drying them means taking the boots apart and hanging all the pieces in a warm and dry location. In a tent they must be hung up high; the temperature close to the floor will be below freezing. As the weather warms up, some people, especially those with dryish feet, back off on this strict regime. Perhaps they just pull out the duffels and leave the insoles in the boots. Perhaps they pull the duffels only after a long day of hard work. At the other extreme, people with particularly sweaty feet will replace wet duffels with dry ones at mid-day.

Something else that is extremely important is maintaining good circulation to the foot. Tight socks or tightly laced-up boots will constrict the flow of blood. Even an extra pair of socks can be the cause of cold feet. It is extremely hard to persuade people that a single pair of nylon socks will probably be warmer than two or three pairs of wool socks - the idea is so counter intuitive. When people wearing mukluks complain of cold feet, the problem is usually due to one of three things: duffles that are not dry, boots that are too tightly laced, or two pairs of socks. Remember that circulation is as important as insulation - perhaps more-so.

For years we thought that the Mukluk was a particularly poor walking boot. The fact that they fit loosely for good warmth means that one's foot will slide around inside, especially once a layer of ice has formed below the nylon mesh. Also, the soles are quite slippery, which makes them very poor for climbing or walking on hard snow. Recently, however, we realized that the loop on the heel of the boot was placed there to help cure the problem of sloppy fit. If the boot lace is passed through the loop and then tied firmly over the instep, the boot will be held much more snugly to the foot. One can, in fact, go for long walks in relative comfort.

Mukluks are often a poor choice for working in and around a town such as Resolute or Alert. They are often too warm, and they are always inconvenient since they have to be removed every time one enters a building. Ordinary shoes and overshoes are usually quite adequate for 'town' life, and overshoes are easily removed at the door.

5.1.2.3 Hands

If a person had nothing to do except stand around, he could put his hands in a mukluk-like bag, and they would stay as warm as his feet. This, of course, is impractical if he is to do anything useful, and compromises must be made. Good quality ski mitts are very warm, as are the military-issue gauntlets, and both allow the use of the thumb. In the past we used the heavy mitts for skidoo driving, but they are hardly necessary any more because the modern skidoos have built-in hand and thumb warmers. Now, we use ski mitts more as emergency hand warmers; they typically are kept in an inside parka pocket and are put on only when our glove-clad fingers get too cold. Our most usual hand covering now is a leather work glove (usually moose-hide) with a light woolen glove inside it as a liner. The leather glove should be large enough that the combination of glove and liner is not tight on the fingers. In practice the glove is usually too tight when it is new, and the combination is quite cold for a day or so. The leather gloves stretch with use, however, and after a couple of days the combination of leather and wool is quite warm, especially if one's hands can be kept out of the wind.

These leather gloves are used as work gloves, and they inevitably get dirty with diesel fuel and sometimes with soot. Usually, two pairs are on the go - the relatively new and clean ones and the foully dirty ones that are used for refuelling and for working on stoves and engines. After a couple of weeks of steady work, the glove will be worn out. In a six-week field trip most people go through several pairs.

Gloves, like mukluks, should be put in a warm place to dry at the end of every day. In very cold weather the liners and the outer gloves should be pulled apart to ensure that they both get quite dry. Once the weather warms up, one can afford to be more cavalier.

We use insulated rubber gloves if our hands are to be in water, and this is particularly the case when we are using our hot-water drill. Under normal circumstances the rubber gloves are not nearly as warm as the leather glove and liner, but they are far superior if the gloves get wet.

After several days of working in the cold, the blood supply to one's fingers seems to increase. The fingers actually swell slightly, and they stay warmer longer. We find, too, that working the big shoulder and arm muscles generates heat that warms the blood that goes to the fingers. In other words, beating your arms hard and fast across the chest until your shoulders get tired will usually warm your fingers. A similar procedure holds for toes, too. When your toes are cold, go for a walk or a run, and keep going until the toes are warm. Don't stand around shivering and feeling sorry for yourself while you shuffle your weight from one foot to the other.

We have experimented with charcoal-burning hand warmers and packages of chemicals that, when mixed, give off heat and warm the hands. They were amusing to play with, but not many people used them more than once. They seem to be more trouble than they are worth.

5.1.2.4 Face and Head

The head is reasonably easy to keep warm, but the face is a problem. The head can be insulated with fur hats, wool hats, toques, balaclavas, etc. Everyone has his preference. One's face, however, is unlike the other parts of the body in that it must be somewhat exposed. For the face to be warm on a cold day, it must be kept out of the wind, and for this a good parka hood is probably the most effective piece of clothing. A good hood forms a long tunnel in front of the face (six inches beyond the nose, say), and the air trapped there forms a barrier to the outside wind. A face insulated by this dead-air gap will generally stay warm. Many parkas, however, have poor hoods that do not extend very far in front of the face, and they need a lot of assistance. Moreover, there are extreme conditions that challenge even the best of hoods. Riding a skidoo at high speed at -40^{0} is the prime example. The dead-air gap cannot withstand the strong wind. The solution to this cold jet of air is usually to wear a facemask that completely hides the face, leaving holes only for the eyes and (sometimes) for the the nose. Masks are made from all sorts of materials: cotton, wool, felt, down-filled nylon and even neoprene wet-suit material. Each type has its admirers, but in general the best one to use is the one that just barely does the job. It is a mistake to get so warm that you sweat.

When skidooing, one usually wears goggles over the mask in order to keep cold air and airborne ice particles away from the eyes. After donning the mask, goggles and parka hood, it is difficult to get underway before the goggles fog over. One needs enough wind to keep the goggles clear, but not enough wind to freeze the face. Practice helps.

When working outside, keep an eye on the state of your neighbour's face. At very cold temperatures and in a bit of a breeze it is very easy to freeze a nose or the skin over a cheekbone and not notice it. The pain, after all, has gone away. Watch for skin that is white and has a waxy sheen to it. When spotted, the frozen part should be heated with a warm hand - a bare hand. Do not rub with a glove; frozen skin is quite fragile. Especially, do not rub with snow; there is no point in thawing the frozen part slowly. A nose or a cheek that has once been frozen should be watched carefully and babied in the future since it will freeze again much more readily. Keep in mind that we are talking here about minor frost nips. A badly frozen part - a foot, for example - is another story; it is a major emergency and should be treated by trained people, preferably in a hospital. We have never had a serious freezing injury, but we have had lots of frost nips.

5.1.2.5 Arms, Legs and Torso

These are the easiest to keep warm. Modern fabrics and insulating fibres have made possible the development of warm, light winter clothes, and the popularity of winter sports has made them readily available and relatively inexpensive. There are, however, many parkas that are not adequate for the bitter cold and the wind of the Arctic. They should be strictly avoided. Saving money on cold-weather clothes is false economy.

Although warmth is the most important requirement for arctic clothes, toughness is also very important. Some of the cheaper modern parkas and windpants have a plastic exterior that rips easily and then leaks feathers or whatever. The parka that we favour is a model called the Snowgoose, made by Metro Sportswear. It is long, well insulated and has a hood that will pull out to form a long tunnel in front of the face. Although it has a nylon exterior it is quite heavy and rugged, and we have had no trouble with it ripping.

It is important not to overdress and get too sweaty, but this has more to do with the vigilance of the individual than the quality of the clothes. As with all outside winter activities, a person should wear several layers of clothes so that he can shed the layers as he warms up. It is uncomfortable to get overheated and wet, and the wet clothes may even be dangerous if warm shelter is a long way away.

For general outside work we often wear some kind of workman's insulated coverall such as those made by Carhartt. They have a tough cotton duck exterior that survives a lot of abuse, although, to its detriment, it is not great at keeping out the wind. One can buy either the coveralls complete with hood or a bib-type overall. The bib overall is particularly useful if one is spending a lot of time inside as well as outside, the heavier coveralls being too hot inside. A jacket or a parka can be thrown over the overall when one goes outside. What we wear underneath depends on how cold it is; usually a warm pair of pants is sufficient. Some people wear long underwear in addition (*e.g.*, polypropylene Blue-Johns), especially on very cold days.

For driving skidoos long distances and for other jobs that may be cold because of the lack of activity, we use well insulated, nylon-covered ski pants. They are better insulated than the coveralls, and they are quite impervious to the wind. They do have the disadvantage that they are not as tough as the coveralls, and they may be too warm if we start working actively.

5.1.3 Eyes - Snow blindness

Snow blindness is a concern, but it is fairly easy to prevent. It is caused by too much ultraviolet light getting into the eye, and it is more prevalent in snowy regions because of all the UV that is reflected from the snow. The symptom is a gritty feel to the inside of the eye, as if it had sand in it. Full-blown snow blindness leaves one blind until it wears off, and the afflicted person is in a fair amount of pain. I have had a touch of snow blindness, and, although it did not blind me, it did make me want to spend as much time as possible inside a dark tent.

Long-distance travellers in the Arctic are particularly prone to snow blindness because they spend all day looking off into the distance or the middle distance - just the angle to absorb maximum UV. Moreover, the ultraviolet comes in from all angles, not just from the area being looked at. This is why the slit goggles worn by the Inuit were effective; they allowed light only from the direction of interest.

We do relatively little travelling, which reduces the likelihood of snow blindness. In camp, one tends to look down a lot, and the view that fills the eye is either a dark-coloured tent or the nearby snow, which, at that angle, is not a great reflector of light. Also, when working in a camp, we spend an appreciable amount of time inside.

Many people wear sunglasses, partly to cut the glare but partly to avoid snow blindness. The words of wisdom here are to ensure that the sunglasses are good ones. Some of the old cheap plastic sunglasses cut down on the total amount of light, but they do not cut out the ultraviolet. Because they cut down the total light, the pupil in the eye opens up to compensate and actually lets in more UV than before. Plastic needs to be specially treated to remove the UV. In fairness, however, recent consumers tests have showed that even very cheap plastic sunglasses now provide excellent UV protection. Glass is safe; it cuts out UV even if it is not tinted.

5.1.4 Miscellany re Clothes

· Polypropylene (Polar Fleece) sweaters or jackets are very warm, and they dry very quickly.

· Bluejohn long underwear (polypropylene) is warm and dry. Dries quickly.

· Do not dry Bluejohns (or any polypropylene fabric) in an electric dryer unless you want them three sizes shorter.

· Mukluks are poor in the wet. Sorrel boots or shoes and overshoes are good for the sloppy, near-freezing weather of late spring. Sorrel boots come in various grades. Make sure that they are waterproof and that they have sufficient insulation.

5.2 Shelter - Setting up Tents

5.2.1 Basics

For most people, living on the sea ice for a short time is an enjoyable experience - or, at the very least, an interesting experience. Like most isolated posts, however, camp life does become boring after a while, especially if there is not a lot of work to do. However, contrary to common prejudice, it is neither uncomfortable nor particularly cold. The tents are well heated and the food can be quite good. Even the absence of regular showers is no great hardship.

Insulated Arctic tents are made by Parkall, Weatherhaven and Polarhaven, amongst others, but the one we prefer for rapid deployment is the so-called 'Octagon', which was designed in-house and built originally in the CFB Esquimalt dockyard shops. (We now buy a commercial version from Weatherhaven.) Because it goes up so quickly, we use it as our 'pioneering' tent at a new camp (Figure 27). Once we are assured of its shelter and warmth we can start putting up the larger and more cumbersome tents. As the name implies, the Octagon has eight sides, and its diameter at the base is about 4.3 m (14 ft). Its sides slope inward, and when it is well guyed it stands up to the wind very well. Like most of the commercial tents, its walls are a sandwich. The Octagon contain about 1 cm of insulation held between the outside layer of nylon cloth and the inside layer of vinyl.

5.2.2 Floors

The first step in setting up a tent is to build a floor. Occasionally, when we have been in a real hurry, we have put up an Octagon on the snow and installed a makeshift floor afterward. However, the only time we do this is when the weather is very cold and windy, and when we have no other shelter. Generally, we put the floor down first. Sometimes we lay the floor on top of a level patch of snow, and sometimes we clear away the snow and lay the floor directly on the ice.

The floor starts with a layer of insulation. Sometimes we use the 1.5-inch blue styrofoam sheets, but in the recent past we have used foil-backed bubble Reflectex rolled insulation. On top of the insulation we put down two layers of OSB (Oriented Strand Board), sometimes called Aspenite. The layers are staggered somewhat so that none of the cracks line up, and then the two layers are screwed together with drywall screws in order to lock the floor into one solid sheet. This raft of OSB board is made large enough that the tent can sit on it comfortably. The 14-ft Octagon, for example, gets a 16 x 16-ft floor. Floor dimensions are always a multiple of 4 ft, since we almost never cut a sheet. We use Oriented Strand Board rather than plywood since the OSB lies flatter. Plywood edges will curl up in time. OSB is slightly weaker than plywood, but it is strong enough. Also, OSB is cheaper.

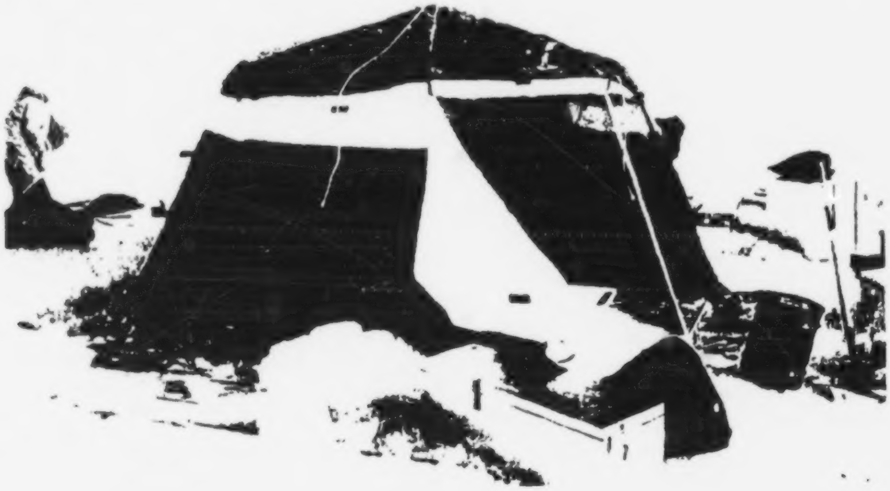

FIGURE 27. An Octagon tent partly taken apart. One of the two wall 'blankets' has been unzipped and peeled away from the umbrella-shaped roof. Note the Oriented Strand Board (OSB) floor.

The sheets are screwed together with a battery-operated drill that has been suitably modified for the cold weather. We have tried several commercially available drills. All of them needed to have their grease removed, and none had a battery that would work for long in the extreme cold. Consequently, we replaced these batteries with a long power lead and a fitting for a 12-V car battery. These lead-acid batteries work well in the cold, and they have a very high capacity. Usually the battery is placed at the centre of the floor, and the work carries on around it.

We find that these floors are strong, well insulated and reasonably flat. They are easy to put together and take apart, especially if the number of screws is kept to a minimum. We have known other groups who have built floors with plywood sheet nailed to a 2x4 framing, but, although the resulting floor was very nice, they took a long time to build, and they had to be burnt when the field trip was over.

5.2.3 Putting up the Tent

Once the floor has been built, the tent construction can begin. Most tents, such as those built by Weatherhaven, require their framing to be screwed to the floor. This is because the arches that form the vertical support want to spring open and push their bottom framing members outward. This push is resisted by the floor, which must, therefore, be screwed together well enough to resist this spreading force (Figure 28). The Octagon is the exception to this rule; it is a free-standing tent that has no natural tendency to splay its legs.

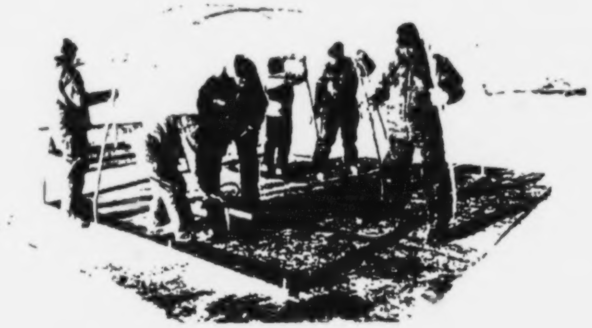

FIGURE 28. A small tent being assembled. The floor framing has been screwed down, and the arches are being put in place.

Once the framework is up, most tents have endwalls that must now be wrestled into position (Figure 29). This is a job for at least two people - preferably three. Following the installation of the endwalls, the main tent cover is pulled over the arches. Again, this job can benefit from a large number of people, some pulling the ropes that pull the cover over the arches, and the others lifting the cover over the framework and generally guiding it into place. The cover is then laced tightly to the endwalls and tied snugly down to the bottom framework members.

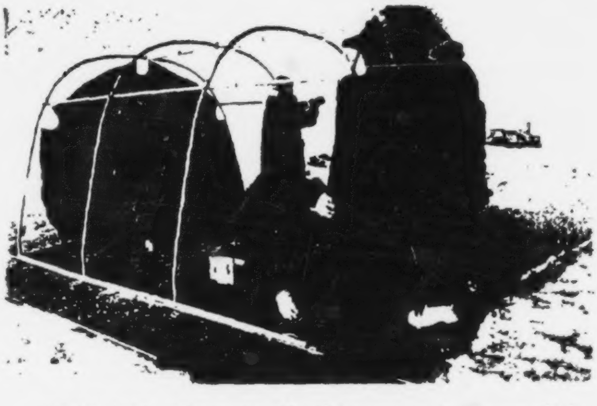

FIGURE 29. The end-walls of the tent are being installed.

At this point, several jobs can go on simultaneously. The snowflaps, which are a lateral extension of the tent cover can be covered with snow. This helps to keep the tent airtight and hold it against a high wind. The heating stove (or stoves) can be installed, together with chimneys, fuel lines and fuel supplies. The tent can be guyed down to the ice. Finally, the beds, tables and other equipment can be brought into the tent.

Keep in mind that modern tent covers are usually made of a plastic, and some plastics behave very poorly in the cold. Many of them become very hard and very brittle. Some of our older octagons, for example, were almost impossible to put up at -40°, a temperature where it is very important to have shelter. The lesson to be learned here is that the tent manufacturer should be closely queried on the nature of the materials he has used. Emphasize to him (or her) the severe cold that will be experienced. Ask for a sample to be cold-soaked and tested at -45° C.

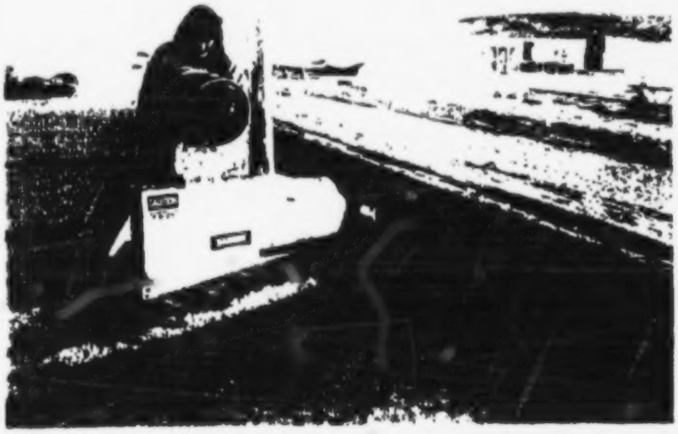

FIGURE 30. Heating the plastic cover of the Widespan shelter with a Herman Nelson. The plastic cover had shrunk in the cold to the point that it would not cover the framework

Another disadvantage of plastics as tent covers is the amount that they shrink in the cold. A tent cover that fits well over its steel frame in the warm weather of the south may not fit at all at very cold temperatures. Part of this is due to the large difference in the temperature coefficients of plastics and steel; a 10-m-long plastic cover will shrink approximately 4 cm more than its steel framework as the temperature drops from +20° C (where the tent was designed and built) to -40° C (where it was erected in the Arctic). The high thermal coefficient is not the only problem, however. Much of the apparent shrinkage is due to the many small creases that form in plastic cloth when it is folded. These creases remain fixed at cold temperatures and effectively decrease the size of the cloth. Figure 30 shows us heating the fabric of a Widespan shelter with a Herman Nelson. As it warmed up, we were able to stretch the fabric into its required shape.

In practice, we ask the manufacturer to cut the plastic cloth larger than he normally would. An increase of 6 inches in 12 ft (or half an inch to the foot) is realistic. The tent may look baggy in the warm, but, on the other hand, it just might go together at -40°.

It is important to have enough light in a tent. Our tent walls (plus the enclosed insulation) are sufficiently translucent that the tents are quite bright inside. This has the disadvantage, of course, that they are bright all night, and some people find it hard to sleep in 'broad daylight'. At the other end of the spectrum, the Americans with whom we worked have berthing tents that are very dark inside. The outer layers in the tent covering are made of black cloth, and one of the insulation layers is an aluminum-covered plastic (probably Mylar). This makes the cover absolutely light tight, and the only light getting into the tent comes through a couple of very small round port holes. These tents were good for sleeping purposes, but they were terrible to work in. The darkness was stygian.

FIGURE 31. A Weatherhaven shelter that has white panels to allow more white light inside. The flooring is visible at the left of the picture, and guy ropes can be seen holding the tent to the ice. The Posi-track is covering the tent flaps with snow - a job usually done by a human with a shovel Two stoves have been installed; the two chimneys and one fuel drum can be seen.

Our early Octagons were entirely covered with red cloth, and, although there was plenty of light in the tent, the spectrum contained only the red; it was far from being white. Long exposure to this would cause some people's eyes to become tired and sore. To try to rectify this situation we incorporated white panels into the later tents. The tent in Figure 31, for example, has alternating bands of red material and white material. This greatly improved the colour spectrum of the inside light, and there were no more complaints. We never went to a completely white tent since we thought that such a tent would be impossible to see from the air. Also, although we may be chauvinistic, we think that the red and white tents are very pretty.

5.2.4 Techniques for Attaching Guys

Tents are nearly always guyed down even if the tent is to be in place for only a couple of days. The rope guys hold the structure from blowing away in a storm, and they also keep the metal framework from twisting and deforming in a high wind. A number of different ways of attaching the guys to the 'ground' have been used, and it is of interest to discuss them briefly.

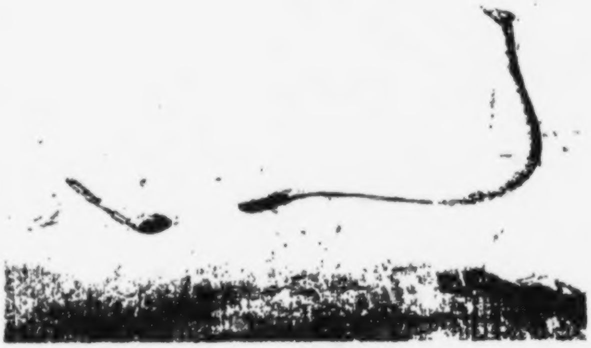

FIGURE 32. Illustration of the preferred tie-down technique. The two holes intersect and form a very strong connection point

The first technique that we used was to drill a one-inch hole into the ice at a 45° slant and to drive a wooden dowel into the hole. The guy rope was wrapped around the dowel and tied off. The result was reasonably effective, but the drill bit was inefficient, and the holes took a long time to drill. Another technique, which works on land as well as on ice, is to bury a 'dead man' in the snow. The guy rope is tied to a board or piece of plywood (the dead man) which is buried in an adjacent snowbank. The disturbed snow becomes very hard in a half day or so, and the 'dead man' is capable of resisting a very hard pull. Finally, the technique that we now use on the ice is to drill two four-inch holes with the Finbore drill (see Section 6.3.1) angled in such a way that the holes intersect six or eight inches down. After the holes are freed of ice chips, a rope is passed down one hole and up the other. The result is an anchor point of great strength (Figure 32). Moreover, the pair of holes take very little time to drill because of the speed of the Finbore. On the ice this technique is really the only one to consider if the four-inch Finbore is handy.

5.2.5 Stoves, Fuels and Hoses

The heating stoves are pot-burners. That is, the fuel just flows down into a pot where it evaporates, mixes with air and burns. The fuel is not blown through a nozzle and vapourized as it is in a household furnace. The rate at which the fuel flows into the pot is metered by a needle valve supplied by a constant-pressure float chamber. This device is often referred to as the carburettor, but it is not like an automobile carburettor. It does not mix air with the fuel; it just meters the fuel. The air enters the burning chamber through a number of holes drilled in its wall. Various tricks, such as the use of hot fins or discs, are used to encourage the fuel to evaporate and to burn completely and efficiently. At one time we built our own stoves, but recently we have been using a model known as the OHR stove made by MIE Stoves Ltd. of Richmond, B.C.

A range of fuels can be burned in the pot stoves, although kerosene seems to behave the best. Diesel fuel is also commonly used, but it is a slightly heavier fuel. In other words, it is composed of slightly larger molecules and has a slightly higher boiling point. This means that it does not evaporate quite so well, with the result that it does not burn thoroughly. When we burn diesel, the stove eventually gets sooted-up and needs to be cleaned - a very dirty job.

It is important that the fuel be formulated for the Arctic. There are, for example, both southern-grade diesels and Arctic-grade diesels. A southern-grade fuel may gel and refuse to flow through the fuel lines. In 1983 at Yelverton Inlet the temperature dipped to -48° C overnight for several nights in a row, and we had trouble with the stoves going out during the night. Having had problems of this kind previously, we blamed ice and ice crystals in the fuel line for our problems. It took two days (and two very long nights) to discover that the kerosene fuel was turning to a gel at those temperatures. Once the problem was discovered it was easily fixed by bringing the kerosene drum inside the warm shelter. It was left there until the outside temperature had warmed up to a relatively balmy -40°. To be honest, we were never absolutely sure that we were actually using southern kerosene; perhaps even Arctic kerosene gels at -48° C.

Very light fuels, such as gasoline, would work in a pot stove, but they are so volatile that their use would be dangerous. We did, at one time, try JP-4, a fuel used in aircraft turbine engines. It is a wide-cut fuel, which means that it is removed from the distillation column over a wide range of temperatures. Consequently, it is a mixture of many hydrocarbons having large differences in boiling temperatures. JP-4 worked well in our heating stoves during the cold weather when the flow of fuel was rapid and the stoves were hot. Our problems began when the weather warmed up and the fuel flow was turned down. The small flame flickering in the bottom of the pot would sometimes get blown out by a downdraft, and this seemed to happen more often with JP-4 than with other fuels. If the fuel were kerosene or diesel the fire would just stay out since the pieces of glowing soot were not hot enough to relight the fire. JP-4, on the other hand, contains some very volatile components, which can be ignited by the inevitable piece of hot soot. The first thing one would hear was a hissing sound, which indicated that the fire had gone out and that the liquid fuel was rising and lapping against hot sections of the stove pot. This was followed a few seconds later by the sound of a loud bang and the sight of the stove lid sailing across the tent. No one was ever hurt, and no damage was done, but after several such explosions we gave up on the use of JP-4 as a camp fuel. Nevertheless, I would happily use it if I were out of other fuels.

The new fuel in the Arctic is JP-8. At Alert, for example, JP-8 has replaced JP-4 for aircraft turbine engines, and DF-8, which is the same as JP-8 except for less strict specifications as to water content, has replaced diesel fuel for engines. The specifications for JP-8 (DF-8) indicate that it has fewer volatiles than JP-4 and therefore should be safer in our stoves. In the spring of 2000 we used it for approximately four weeks in seven heating stoves, and we were quite encouraged by the results. It closely resembles kerosene in its cold-weather viscosity and its clean-burning characteristics. On two or three occasions a stove went out inadvertently, and there were no explosive ramifications.

The hose that feeds the fuel from the barrel to the stove is another important item in the extremely important job of getting a fire going. Most flexible hoses that will work well in warmer climates will turn bar-hard at -40°. If forced, they will break. Many times I have stuffed a coil of fuel hose under my parka and waited until my body heat had made it flexible enough to lay out between barrel and stove. In recent years we have used a product called Ortac, which is flexible at Arctic temperatures. We found that 1/4-inch hose was too small and too weak, and we now use 3/8-inch hose.

After connecting the stove to the fuel barrel, the camper's next job is getting the fuel to run. One would think that this just a matter of letting gravity do its thing, but several problems can conspire to thwart the fire lighter. First of all, the hose is generally laid out in coils on the floor, and in such a configuration the hose will not fill uniformly. The bottoms of the loops fill with fuel while the tops of the loops still have air in them. After a while the hose contains three or four slugs of fuel trying to rise simultaneously in their respective coils, and the pressure due to the height of the fuel in the barrel is not sufficient to lift all of them together. The solution is to get rid of all the air bubbles. We open a valve at a tee on the stove so that the fuel will flow rapidly into a beaker - if ever it starts to flow. Then we flatten the hose coils on the floor so that none of the fuel is being lifted. If, after a reasonable length of time, this hasn't worked, we turn and twist the hose in order to move the bubbles along and encourage the fuel to move. When it does start flowing, we let the oil run long enough that we are assured that the bubbles have all been purged. Generally, this means that we fill the small beaker. We then turn off the valve and let the fuel flow into the carburettor. We dump the contents of the beaker into the stove and light it, and if we are particularly lucky, the fuel starts flowing into the stove pot before this fire goes out. Sometimes the float or the valve in the carburettor sticks, and we have to take it apart in the cold in order to free it up. Luckily, this hasn't happened often.

A situation that used to occur quite regularly was that the fire would go out after having burned quite well for an hour or so. This problem was frustratingly difficult to solve the first time it happened to someone, but after that it was just an embarrassment. The fuel stops flowing if the camper forgets to loosen the top bung of the barrel. As the fuel level drops, a partial vacuum is produced in the barrel, and this eventually stops the fuel from running, and the fire goes out. We now have special bungs that we install after the barrel goes up on its stand. These bungs have small holes drilled through them to let the air pass. In order to keep the snow from blowing into the hole, a short tube is welded into the hole and a piece of hose (20 cm, or so) is pushed over the tube and let hang downwards. This lets the air in but keeps out all but the most persistent snow crystals.

5.2.6 Stove-pipes

There is a right-way-up and a wrong-way-up when it comes to installing stove-pipes, and most stoves are built so that the pipes are installed the wrong way up. I realize I am maligning the stove-building fraternity, so let me try to justify the statement. Stove-pipes are inevitably made up of several sections fitted together, and the problem arises because each section is oriented so that the female end is facing downward and the male end is facing upward. I imagine that people think that this is the best way to keep the uprushing smoke inside the pipe. If the pipe fitting were the other way up, so the thinking goes, the smoke might drive its way out of the poorly fitting joint and get into the room. This, of course, is not true since the pressure inside the pipe is lower than the pressure in the room; moreover, the velocity of the exhaust fumes is quite low.

In most parts of the world, the orientation of the stove-pipes is irrelevant since very little creosote or water condenses in the stovepipe. In the Arctic however, the condensation is appreciable. The top two or three feet of stove-pipe stick up into the frigid air above the tent, and, since the uninsulated metal pipe is a good heat conductor, a lot of water vapour in the exhaust gas condenses onto the inside pipe wall. As this water runs back down the stove-pipe, it mixes with creosote, soot and other foul things. If the stove-pipes are oriented the usual way, this black fluid is channelled out of the pipe at each joint. The dirty water then drools down the outside of the stove-pipe where it looks ugly, gets hot and smells.

If the stove-pipe is turned end-for-end, according to the thinking of informed Arctic campers, the black mess is kept inside the stove-pipes, just as shingles keep water out of a house. The fluid eventually gets down close to the stove where it re-evaporates and tries once again to get up the chimney. The net result is that the outside of the stove-pipe - the part that you can see in the tent - stays absolutely clean. And, really, no smoke ever leaks through the joints.

However, it is not a simple matter to install stove-pipe the 'right' way up since the commercial stoves come equipped with a fitting that attaches to the female end of a pipe. One is forced to install the piping with the female end down. To overcome this we have modified our commercial stoves so that they accept the male end of the stove-pipe. The stoves we designed in-house were built 'correctly' from the beginning.

Our stoves use four-inch-diameter pipe, and, wherever possible, we use four-foot lengths for convenience. The alternatives are two-foot lengths, which we find to be inconveniently short.

Because the pipes get so very sooty, they befoul everything they touch once the camp is broken down. Consequently, we throw them out at the end of each season and use new, clean ones the following year.

In 1997 we had an unfortunate incident involving stove-pipes. We temporarily abandoned a camp while we did some work elsewhere, and we left the heat on in one of the tents in order to keep some electronics warm. A storm came up that night and blew for two days. When we finally got back to the camp we found that the wind had caused the stove-pipe to 'work' until two sections had separated. The stove continued to burn, and for hours it belched sooty oily smoke into the tent. Everything was contaminated. The tent and all the electronics looked and smelled horrible, and it took us a very long time to clean up the mess. The lesson we learned from this was that if a stove has to be temporarily abandoned while it is still operating, the stove-pipes should be screwed together with sheet-metal screws. The next year we went rather overboard in screwing everything together.

5.2.7 Camp Layout

We keep several things in mind when it comes to laying out the camp. First of all, the tents should not be too close together. We want them far enough apart that if one tent should burn, the fire would not jump to a neighbouring tent. Secondly, if the tents are close together, the wind-blown snow will drift in between them quite badly. The downwind tent, in particular will collect a lot of snow. For this same reason we like to lay out the tents roughly in a line perpendicular to the storm winds. If this is done correctly, no tent is directly downwind of another. The direction of the strong winds can sometimes be determined by looking at the direction of the predominant sastrugi - the drifts of snow that have been piled up by the wind. Note that the sastrugi lie along the wind direction, not across it as do the waves in water and the ripples in sand.

Equipment that is piled outside can easily be lost in a snowstorm (Figure 33). After a storm all small and medium size boxes will have completely disappeared. Only a smooth white landscape will meet the eye. For this reason we pile all equipment in a line across the expected wind direction, and we stick a bamboo pole in the snow at both ends of this freight line. The bamboo poles indicate the limits of the shovelling that will have to done later. Good 'housekeepers' will keep the freight line neat at all times; poorer ones, like me, will haul everything back into line just before the storm hits. But even I will make sure than nothing is left by itself out in the open. Remember that any boxes left by themselves and unmarked (by a bamboo pole, for example) will almost surely be lost. Hours of frustrated shovelling can be spent looking for the wayward boxes. I know.

5.2.8 Portable Shelters

Although all tents are portable to some extent, some are more portable than others. Occasionally we need a heated shelter that can be moved rapidly from place to place - usually from ice hole to ice hole. The crudest model was essentially a large plywood box fastened to one of our sleds. It was heated by a kerosene space heater without a chimney, and it was just large enough and warm enough for one person to crawl inside and splice cables. This was named the 'Sooke Caravan' in (dubious) honour of Jim Perkins, who used it the most and who happened to live in Sooke.

FIGURE 33. Snow blowing and drifting in a strong wind Note the long drift that has formed downwind of the tent on the left.

A more luxurious habitation is known as the tent-on-a-sled (Figure 34). This tent, which is made by Weatherhaven, has internal dimensions of about 8 x 12 ft. Its stove has a chimney, and it can be pulled quite handily by a large skidoo.

Our other very portable tent is the one kept in our emergency sled - the one we keep nearby in case a moving ice ridge crushes our camp (see Section 5.7.8). Each sled has two 'Moss' tents that are very light and quick to set up - although they are complicated enough to set up that the procedure should get some practice. Figure 35 shows the two tents set up on the snow.

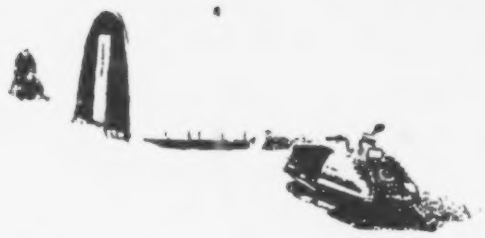

FIGURE 34. A tent-on-a-sled being pulled by a Nordic skidoo The skidoo riding behind is acting as a brake. It prevents the tent from over-running the lead skidoo on the down-slopes.

5.3 Communications

FIGURE 35. Practising the technique of setting up emergency tents.

Good communications between an ice camp and the base location (*e.g.*, Resolute or Alert) or between parties on the ice are very important, and in some cases they are vital. First, and most importantly, there is concern for the safety of the people at the ice camp. If there should be an accident, or if the ice starts to break up, the people on the ice need to be able to call for help. Secondly, the weather conditions, as reported by the ice camp, are very useful to the aircraft pilots. Finally, almost all experiments rely on two parties being able to talk to each other.

Most communications between base camps and ice camps is by High Frequency (HF) radio. (Officially, this encompasses the frequencies between 3 MHz and 30 MHz.) This band is used because radio waves of those frequencies can skip off the ionosphere and propagate for long distances. It is often the only communication channel that has a hope of doing the job. Because conversations on HF radio can be heard for such long distances, it is important that proper radio protocol be used. One aspect of this is to use proper call signs. We have been officially issued the series of call signs CYZ80, CYZ81, etc. up to CYZ89.

Although the HF is good for long-distance communications, it does have its disadvantages. Clarity of reception, in particular, is often poor. Single-sideband modulation, which is used to get more power into the 'information' side-band rather than into the carrier, causes frequency distortion. That, plus radio noise, can seriously reduce intelligibility. Sometimes, because of poor 'readability' conditions, only the most basic messages can be passed - such as 'all is well'. The important topics (the reporting of weather, for example) have a strict order and format in order to make the information easier to understand. It was for HF radio that the phonetic alphabet for letters (alpha, bravo, charlie, etc.) was developed. Unless radio conditions are particularly good, complex discussions are out of the question.

HF radio occasionally suffers from 'black-out' conditions in which no signal at all gets to the receiver. These conditions are generally associated with strong sun-spot activity, which causes disturbances in the ionosphere. Several years may go by without a 'black-out', but when one does occur the HF traffic will be wiped out for a week or more. And, for the first day or so, everyone thinks the problem is with his own radio.

Very-High-Frequency (VHF) radio (30 - 300 MHz) has somewhat different characteristics. Its great advantage is its clarity; it is generally as good as a telephone. The output is a modulated carrier, rather than a single sideband, and this improves the clarity. Also, VHF often employs frequency modulation (FM) rather that amplitude modulation (AM), and this usually has less noise associated with it. (Note, however, that VHF communications on the Air Band - between aircraft and between the ground and air - use AM modulation.) The chief disadvantage of VHF is its short range. It is useable only within line-of-sight, which means that two people with hand-held radios will not be able to talk to each other if they are more than about 5 miles apart. Even then, they usually have to stand on a box and hold the radio high. For a project north of Alert, however, we managed to increase the communication distance to 180 km by installing a VHF repeater on the top of a high hill (600 m or 2000 ft) near Cape Joseph Henry, which is 40 km north of Alert (Figure 36 and Figure 15).

When an ice camp is first established, one of the first jobs is to set up radio communications. This usually happens immediately after a tent is up and the heat is on. The radio transmitter is brought inside to warm up, and then an antenna is installed. The antenna we use for HF is a centre-fed half-wavelength dipole. At the frequencies we use (4500 to 5000 kHz) the antenna length is about 30 m. We support the centre and both ends with bamboo poles appropriately guyed down to the snow or ice. The centre pole is placed close to the tent so that the co-axial cable can reach from the radio to the antenna.

We find that the radiated signal does not depend measurably on the orientation of the antenna. The dipole is so close to the ground (perhaps 3.5 m, or 0.06 wavelengths) that it exhibits a radiation pattern that is almost omni-directional. Since we don't have to orient the antenna in any particular direction, we simply place it so that it is reasonably close to the tent but out of the way of the traffic.

FIGURE 36. VHF radio repeater sited on the top of 'Merv's Peak', a 600-m (2000-ft) hill near the north coast of Cape Joseph Henry, Ellesmere Island The camera is looking south-west

Because of the safety value of good communications, at least two radios are taken to each ice camp - one for backup.

A mobile field party that wants to use HF radio will often try to avoid setting up a half-wave antenna since the procedure is so time-consuming. If the distances are not too great, they can often get by with a vertical-whip antenna. However, since the whip is so short (in relation to a half wavelength), it presents a very reactive load to the output stage of the transmitter, and so the output matching network of the radio must be tuned in order to maximize the radiated power. Anyone going out with a field party should be shown how to tune the antenna.

Sometimes the radio signal emitted from a whip is just too weak for the distances involved, and the field party is forced to set up a half-wave antenna. However, they still can save some time by elevating only the centre of the antenna and not the whole thing. The two antenna wires leading from this central junction are just draped downward from the bamboo pole onto the ice. The installation of one bamboo pole does not take very much time. It is just stuck into the snow, and it does not have to be guyed. Moreover, the radiated power is reasonably good since the important part of the antenna - the high current section - is the part that is elevated. What seems to take most of the time is laying out the wire on the ice and then winding it back up again afterward. It pays to use very flexible wire for the antenna - such as light 'braid'.

When we use VHF radio at an ice camp, the 'base-station' radio uses a vertical whip with ground-plane as its antenna. The whip and the ground-plane wires are only about 0.5 m long, and so the whole structure is quite light. Because line-of-sight depends so strongly on antenna height, we endeavour to get the antenna as high as possible. As a minimum, we lash two bamboo poles together (with hose-clamps or black tape), and lash the antenna to the top of this combination. If it is available, we use a telescoping aluminum pipe-mast, which will support the antenna about 10 m above the ground. The mast is placed reasonably close to the 'radio' tent, and it is guyed to withstand the storm winds.

The power supply for the HF radios and for the more powerful base-station VHF radios is almost always a 12-volt car battery. With moderate use, a car battery will last for about a week. Sometimes these batteries are recharged in camp with a portable generator and battery charger, but sometimes it is more convenient to send them back to the base camp for recharging. In that case, a small stock of batteries is kept out at the ice camp.

In the past our hand-held VHF radios were all powered by alkaline AA batteries. Rechargeable NiCad battery packs were available for most of these radios, but they weakened quickly in the cold, and each charge did not last very long, especially after the battery had aged a year or so. The primary alkaline batteries had a higher energy density than the NiCads and seemed to work better in the cold. Regardless of which batteries are used for the VHF radios, they should be backed-up with spares.

The future for communications in the Arctic looks quite interesting. Satellite telephone systems that promise pole-to-pole communication are even now being installed. The Iridium system was very useful to us on two Arctic field trips - in 1999 and 2000. Unfortunately for us, however, it has declared bankruptcy and is presently being dismantled. Undoubtedly, other systems will be more successful. Once they are in place, a person in the middle of the Arctic Ocean will be able to lift a telephone and call anywhere in the world. However, pizza delivery is still going to be a problem.

5.4 Food and Cooking

In the absence of nearby pizza parlours and other fast-food joints, we have had to do our own food preparation. In a small camp of two or three people, we try very hard to keep this simple since the cooking and the cleaning-up represents time that must be taken away from doing 'useful' things. We pack a primitive kitchen - pots, dishes, cutlery, etc. into one large aluminum box. When this so-called 'kitchen box' is unpacked it serves as shelves and a support for a counter. Figure 37 shows this kitchen set up in a 'corner' of an octagon tent. We cook on a two-burner propane stove fed by a 20-lb propane bottle. Rather amusingly, the bottle must be kept inside the tent to keep its pressure up. Propane condenses at -40° C, and at temperatures below about -30° C the vapour pressure of the propane is too low to keep the stove's flame lit.

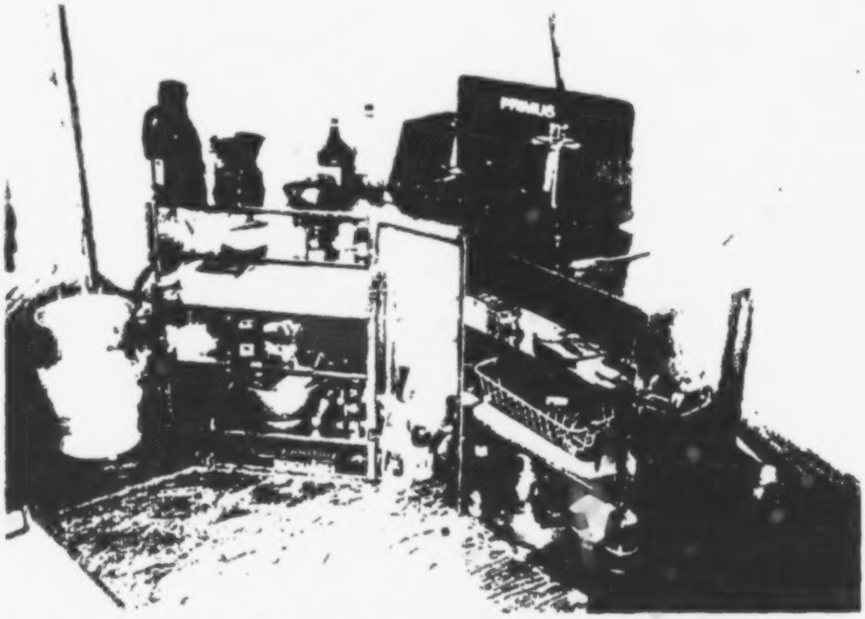

FIGURE 37. A 'kitchen box' that has been opened up in a corner of an Octagon. The stove burns propane, which must be kept inside to maintain pressure in the tank.

We eat food that is easy to prepare and that can be kept in the cold. A steak or a chop plus rice and a frozen vegetable are standard fare. Canned soups and stews are easy to prepare, as are sandwiches made with sliced meats. Ice cream and cookies or frozen cakes are popular for deserts. Chocolate bars are popular anytime. We generally do not try to use potatoes, fresh fruits or fresh vegetables since they have to be carefully handled and stored to keep them from freezing. We concentrate on quantity and quality rather than on variety. Long hours in the cold give us ravenous appetites, and everything tastes good.

In a larger camp the variety can be much greater. We hire a cook (and sometimes a helper) who can focus entirely on producing meals. A whole tent (sometimes a large one) is set aside as a mess hall. An oil-burning range (sometimes two) and a large collection of cookware is set up in the mess hall. Inside this tent the cooks can also store the perishable foods that are generally not brought out onto the ice. Their professional pride is a strong inducement for them to provide a wide range of meals, and their professional skill generally makes it possible.

In a camp of any size - large or small - a supply of fresh (*i.e.*, non-saline) water is a continuing requirement, and it is by no means easy to acquire. Usually we obtain our water by melting snow. We do this in a large container that is propped over the stove that heats the tent. There is no particular advantage in melting ice rather than snow; both require the same amount of heat to produce a unit of water. Moreover, chipping ice is hard work, whereas shovelling snow is easy. The only disadvantage of snow vs. ice is that a larger volume of snow is necessary to produce the same amount of water.

The job of keeping a supply of fresh water on hand is particularly hard when the camp is large and when the cook is not used to conserving water. Whenever possible, therefore, and particularly when there is a cook, we transport water in plastic 'jerry cans' from the base camp (*e.g.*, Alert). This works well if there is a regular shuttle (every two days or so) between the main camp and the ice camp.

5.5 Sleeping Accommodations

Our sleeping arrangements have always been fairly primitive. We don't fuss with sheets and blankets; we just use sleeping bags. In the very early days we would just put a couple of foam mattresses (known as foamies) on the floor of the Octagon and sleep on them (Figure 38). However, the floors of an Arctic tent are very cold. For example, the ice cream was often stored inside the tent up against the wall since the temperature there was just right. (Ice cream left outside would freeze to a rock-hard spoon-bending consistency.) The floor is so cold that by morning a foamie mattress would be frozen to the floor - frozen with the moisture perspired by the sleeping body. Occasionally, too, a sleeper who migrated off the mattress at night would waken with his beard frozen to the plywood floor.

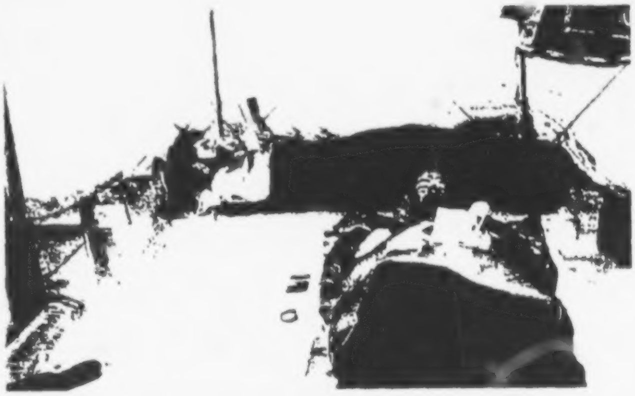

FIGURE 38. Early sleeping arrangements in Octagon tents. Here we have Doug Schneider (at the back) and Jim Perkins catching up on their reading

After putting up with this for some time, we awoke to the fact that we would be much warmer and more comfortable if we raised ourselves off the floor at night. It is not for nothing that the Inuit build sleeping shelves in their igloos. We bought small IKEA cots, which were light and easy to put up. Not only were we warmer and more comfortable, but we could actually turn the stove down and use less fuel. It was still reasonably cold, however, and body moisture still condensed in the foamies. This meant that when we packed up the beds during the day we had to store our sleeping bags and foamies up off the floor so that they could dry. Otherwise, they would be damp and cold the next night. If space in the Octagon was at a premium, the IKEA cots would be folded up and stacked outside during the day, and the table and chairs would be brought back in. Sleeping bags and foamies stayed inside.

When the camps were larger, we could often allocate a large tent just for sleeping purposes. Our American colleagues call these 'berthing tents', and we used to tease them about their need for a maternity ward. These tents, which could be as long as 28 ft, were usually heated with two stoves. Those who liked to be warm at night could usually find a place close to a stove, while those who liked to be cool could also find a spot to their liking.

Most of us take two sleeping bags to the Arctic - a heavy one and a lighter one. The light one is used regularly for sleeping in the tents. The heavy one is used only as an emergency bag. There is an unwritten rule in the Arctic than whenever you go flying you take along a heavy emergency sleeping bag just in case you get stranded. Luckily, I've never had to use mine.

5.6 Sanitary Arrangements

When we set up a camp, one of the first things that we do is estimate the direction of the prevailing winds. We use this to help decide where we are going to get snow for drinking purposes, and we usually pick a spot upwind of the tents and their soot-emitting chimneys. To keep this snow clean and reasonably sanitary we mark off a suitable area and ask people not to walk through it. We then set up a P-pole a fair distance downwind of the drinking snow. The P-pole is usually a small stake or a few feet of bamboo pole. Everyone (except for any women) is then requested to urinate by the P-pole so that there is only one unsightly spot and not a multitude of them. (As yet no-one has remembered to bring a rubber hydrant.)

Once we get a spare moment in the buildup of the camp - or, perhaps, when the moment is thrust upon someone - we set up a small tent for a toilet. We used to build an igloo complete with throne. More recently we have used a small uninsulated tent called a 'Hurritent', which is named for the speed that it could be erected and not necessarily for our particular requirement (Figure 39). The framework of the Hurritent is a coil of steel rod. This framework opens and closes in a manner that brings to mind the toy called a 'slinky'. Regardless of the construction of the 'outhouse' the structure is always named after that great friend of civilization, the inventor of the flush toilet - Thomas Crapper.

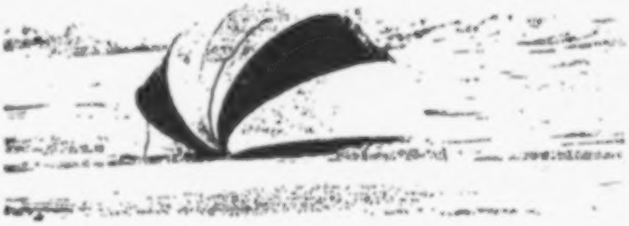

FIGURE 39. A small Hurritent, with its 'slinky'-like frame and thin plastic cover This one was used as our toilet.

The Hurritent, besides being quicker to put up than an igloo, was also roomier, lighter and warmer (because of the solar heating). A disadvantage to this extra warmth was the extra smell, which offended the sensibilities of some. As a result, the throne was modified so that each visit involved a separate garbage bag. When he (or she) was done, he tied off the bag and put it outside the tent. When a large number of bags had collected, someone would take them (and their frozen contents) a mile or so away, drench them with diesel fuel and burn them. This burning was to protect the environment from the plastic garbage bags - not from their contents.

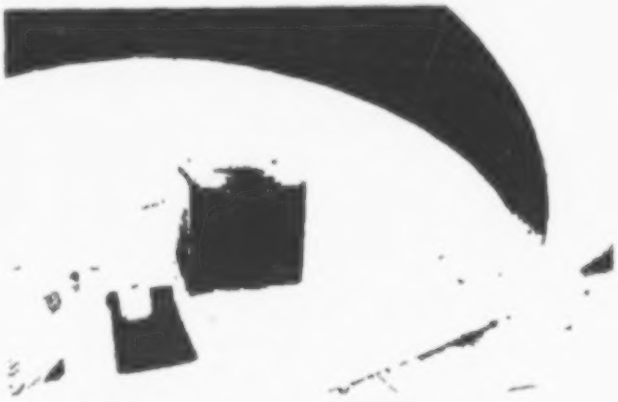

FIGURE 40. An inside view of the Hurritent showing the 'throne' made of a wooden box and topped with a blue styrofoa seat. The square plastic bucket inside the box is lined with a garbage bag. This bucket and bag can easily be removed and renewed.

Our first throne seats were made of plywood, and, as most old-timers from the prairies know, wooden seats in outhouses are very cold in the winter. A little pain is good for innovation, however, and we soon discovered that a styrofoam sheet makes an amazingly warm seat, even at -40°C (Figure 40). Because styrofoam is such a good insulator, its surface warms instantly to body temperature. White styrofoam, however, does not show the light dusting of snow that the wind sometimes carries in, and the poor innocent who sits on this snow gets a very rude shock. Very quickly we switched from white styrofoam to blue.

5.7 Safety

5.7.1 General Philosophy

Safety in the Arctic is a major concern. There are many possible ways to get hurt on a field trip, and, unlike the south, ambulances and hospitals may be days - not minutes - away. Even warmth and relative safety may not be nearby if one is on a skidoo trip. Someone working alone who passes out from an illness or an accident might die from the cold before he is discovered.

However, it has been our philosophy that a long list of safety rules is not what we need. The important thing is that people understand the rather dangerous nature of the Arctic environment and that they think about what they are doing and whether or not it could cause them (or someone else) an injury. Education, discussion and common sense should tell them what is safe and what is not. A list of rules will not protect the workers from everything that can arise. On the contrary, it may give them a false sense of security, which is dangerous. A feeling for self-preservation must come from within; it cannot be imposed from above.

Education is the most important tool for giving people a feel for safety. Everyone should be shown how to handle equipment in a safe way. They should be shown how to use shotguns, rifles and bear-scaring explosives - either in a formal course before they go north or (as a minimum) by an experienced person in the Arctic. They should have a knowledge of First Aid and, preferably, should hold an up-to-date First Aid ticket. The training we have found to be the most appropriate is Wilderness First Aid since it prepares the student to handle emergencies when there is little prospect for early evacuation. One of the pieces of equipment that is sent out as part of the basic camp set-up is a well equipped first-aid box.

Although good common sense is the best guide for keeping oneself safe in the Arctic, there are some unwritten rules. One of the most important is that everyone who goes flying shall take along an emergency sleeping bag. It would be such a shame to survive a crash and then to freeze to death or die of shock that is made deadly by the cold. Generally, everyone who goes flying makes sure that all the others have brought bags. It would be annoying, to say the least, to have to share a bag.

The other important guideline is that no-one should be all by oneself for long periods of time. In particular, this means that on a long skidoo trip there should be at least two people and two skidoos. The travellers should have a radio, and they should check-in at regular intervals. If a person must go by himself, he should definitely have a radio, and he should let someone know when he expects to arrive at his destination. Moreover, this safety person should take his function very seriously. At the prescribed time he should check that the traveller is, indeed, where he said he would be. If he is not, a rescue mission should be sent out (weather permitting). Moreover, the traveller should understand that if he does not check in promptly he will cause a lot of unnecessary worry and trouble to others.

Staying overnight in a camp by oneself is also looked upon with some disfavour, but it happens occasionally.

What follows is a discussion of some of the dangers of living and working in the Arctic.

5.7.2 Aircraft

Probably the most dangerous piece of machinery in the Arctic is the spinning rear propeller on a helicopter. It is just the right height to remove your head and shoulders, and it is completely exposed and unguarded. To make matters worse, the running helicopter is surrounded by an atmosphere of mind-numbing noise, of very cold winds and of an irrational desire to hurry. The ridiculously long main blade whop-whopping overhead commands your attention at all times. Thus, it could be very easy, as you are hurrying away from all that noise and unpleasantness, to forget your training and run straight into the rear propeller blade, which, after all, is not making any noise and which is going so fast that it is almost invisible. This danger is very real; too many people have been killed this way.

The number one rule when working around a running helicopter is that you approach it from the front and that you leave it toward the front. More precisely, you approach it and leave it in such a way that the pilot can see you. Before approaching the helicopter, you wait until you catch the pilot's eye. He will give you permission to approach by nodding or beckoning.

When you are working around a helicopter, some pilots do not like you to go aft of the main doors. This means that the storage compartments in the after fuselage should be loaded by the helicopter mechanic. In practice, once the pilot knows you well enough to realize that you have a healthy fear of the rear propeller and that you maintain your cool around his machine, he will let you load and unload the rear compartments. But, if he is nervous, don't push to do things that he thinks are dangerous.

The main propeller on a helicopter, although it is directly overhead, is not as dangerous. Under normal circumstances it is much too high to pose any danger to even the tallest of basketball players. Moreover, its menacing 'whop, whop' causes people to approach the machine in a stoop or a crouch. There are, however, two circumstances in which the main prop can be a danger. The first occurs during shut-down. When the propeller has slowed to a rotation of, say, one rotation every one or two seconds, it has lost much of its gyroscopic stability. A sudden gust of wind during this period could cause the propeller to tilt sharply to one side - lowering the propeller tip to less than six feet off the ground. When the blade is moving slowly you are well advised to stand outside its reach, or, if you are already standing beside the helicopter, to stay there until the propeller has come to a full stop. The other scenario that can be dangerous is uneven ground around the helicopter. For example, the helicopter may have landed on rising ground, or there may by snow drifts around the landing spot. Since the propeller tends to spin horizontally, even if the helicopter is sitting on a slope, the blade tips will come closer to the ground on the upper side of the helicopter. If there is any doubt, approach and load the helicopter from the lower side. And, keep off the snow drifts.

Try to remember during all the confusion and mind-shattering noise: keep calm, don't hurry, and don't make sudden movements. The helicopter is there to serve you – not the other way round. Keep thinking.

Fixed-wing aircraft, such as the Twin Otter, also have propellers that can turn the upper body into ground meat. Again, these propellers are almost invisible when they are running fast, and it would be very easy to walk or back into one of them. The pilots worry, of course, and they like to see that you have a procedure and a sense of discipline when working around their machine.

The freight door on a Twin Otter is on the left side of the machine, and the port engine is always stopped when any loading or unloading is going on. The starboard engine is usually kept idling in order to ensure that port engine can be started later. Stay away from the starboard side. Approach the aircraft from the port side behind the wing, preferably after the engine has come to a complete stop.

Even when the propellor is stopped, the pilot will often station one of his crew by the propellor when the aircraft is being loaded. This is partly to keep people from walking into the (stationary) propellor, but it is mostly to keep people from hitting - and damaging - his propellor with the equipment that they are loading onto the aircraft.

5.7.3 The Cold - Frostbite

Frostbite is probably the most immediate danger of working in the Arctic. It is discussed in some detail in section 5.1.2 under the heading 'Keeping Warm'.

An associated danger that is well known to children of northern climates is to keep your tongue and lips away from cold bare metal - flagpoles, axes, etc. It is very easy to forget this and, for example, blow on a piece of copper fuel line in order to clean it out. If the pipe is small, you may not actually lose a piece of skin, but you will be left with a 'burnt' lip that will hurt for several days to remind you of your folly.

Also, be very careful with liquor that has been in the cold. Whiskey, for example, is quite liquid at -30°, and it looks no more treacherous than whiskey usually does. However, a large swallow, thoughtlessly taken at this temperature, can freeze the throat and the inside of the mouth.

5.7.4 Fire

If suitable care is taken, the probability of a fire is not high. However, the possible effect on life and property is so severe that fire is a major concern. To my knowledge, we have had one tent burn due to spilled gasoline from a two-burner gasoline cook stove. I was directly involved with another fire in a wooden building. It was caused by leaky joints in the plumbing of one of our DREP heaters. The fuel dripped into a pan, got overheated and ignited.

We keep fire extinguishers in a convenient location in all buildings and tents. The shipping box for every heating stove contains an extinguisher as a standard item. New people should be shown where they are, and everyone, at some point, should be given some instruction and practice in the use of extinguishers. When the fire is raging and your heart is pounding you don't want to start learning about how to use the equipment.

It should be emphasized that snow is an excellent fire extinguisher, and there is lots of it in the Arctic. It both smothers the fire (cuts off the oxygen) and quenches it (cools it below its ignition point). Unlike water, it does not run underneath burning petroleum products. It soaks up the burning fuel like a sponge and quenches it. The fuel oil fire mentioned above was put out by snow. A fire extinguisher was, indeed, hanging on the wall, but the shovel and the snow were handier since I was outside when I saw the fire.

Protecting oneself against fire should start with a knowledge of what is dangerous and what is not. Most particularly, hot liquid fuels are dangerous. Gasoline at room temperature is dangerous. Cooking oil on a hot stove is dangerous. The common thread to this is that fuels that are at or above their flashpoints are dangerous. The flashpoint is the temperature at which the fuel will ignite if a flame or spark is presented briefly to the vapour above the liquid.

Gasoline, which contains volatile compounds, has a fairly low flashpoint (about -43°); hence it is dangerous. However, even it is harder to ignite at low temperatures - as evidenced by the fact that gasoline engines are notoriously hard to start in the winter. Kerosene and diesel fuel, which are mixtures of less volatile hydrocarbons, have flashpoints somewhere between 100 and 160° F (40° - 70° C). This means that at -40°, which is far below their flashpoints, they are very hard to light. One can, in fact, extinguish a match in liquid diesel at that temperature. We even found it very hard to light ethanol (flashpoint 21° C) at -40°. We used ethanol (ethyl alcohol) to preheat our kerosene-burning Primus stove, and at very cold temperatures the ethanol would actually put out the match. To get the alcohol started we would hold the match under the little metal priming pan and warm up the alcohol. Eventually a small dot of flame would light the surface of the alcohol and this dot would slowly expand until the whole surface was burning.

The point of this is not to make people more cavalier about fire; rather it is to make them less paranoid and to give them a better understanding of what is dangerous and what is not - and why. Your safety considerations should be spent on things that are truly dangerous; don't waste your time worrying about cold diesel fuel exploding.

5.7.5 Humidity

In cold climates the air inside buildings is usually very dry. Although this is not dangerous in the strict sense of the word, it can be unhealthy because nasal passages become quite dry, and this is an open invitation to a cold virus. Dry skin is also a problem that is caused by the low humidity.

The relative humidity of the air can be estimated from Table 4, which gives the partial pressure of water in saturated air as a function of temperature (taken from the Chemical Rubber Handbook of Chemistry and Physics).

TABLE 4. Water Content of Saturated Air

Temperature (°C)	**Partial Pressure of Water (mm of Hg)**	**Weight of water in air. (gm/m^3)**
-40	.097	.11
-30	.286	.30
-20	.776	.82
-10	1.97	2.06
0	4.58	4.84
10	9.21	9.74
20	17.54	18.55

Air at -40° is capable of holding a maximum of 0.11 gm/m^3 of water. If this air is brought inside and heated to 20° without any addition of water, the water content will still be 0.11 gm/m^3 or less, even though it is now capable of holding 18.55 gm/m^3. At most, therefore, the relative humidity is 0.11/18.55 = 0.0059 or 0.59%. This is exceedingly low. As a comparison, the Encyclopedia Britannica says this about the humidity in the Sahara Desert: ‘During the summer months...the relative humidity (with a mean value of 30 percent) can fall to the life-endangering value of 2.5 percent, the world's lowest.’ This life-endangering relative humidity may be the ‘world's lowest’, but it is still four times that found in a heated unhumidified Arctic building. Therefore, for health reasons it is important to humidify the air.

A room that is, say, 3 x 4 x 3 m could hold 668 gm of water at 20° C. It would take about half of that, about a third of a litre, to produce a comfortable atmosphere - neglecting what the dry walls and carpets would absorb. Since the air is continually being exchanged with dryer air, it is evident that water needs to be evaporated at a considerable rate. In Alert, for example, we install a humidifier in each small dormitory room, and we also put a humidifiers in each hallway. The small ones evaporate a gallon or more of water per day, and the large ones in the hallways go through 10 to 15 gallons per day.

In spite of the efforts to humidify our living spaces, most people suffer, at least slightly, from split skin, especially on the fingers. It is a good idea to use a good quality skin cream on one's face and hands. Moreover, in an effort to keep the face from getting sun burnt, it is wise to use a cream that incorporates some sort of sun block.

5.7.6 Animals

5.7.6.1 Polar Bear

Of all the Arctic animals, the Polar Bear is the most dangerous to people. He combines great size, strength and speed with an unpredictable nature. The 'Polar Shelf' web site at http://www.nrcan.gc.ca/ess/pcsp/profpage/opsman/opsman_e.htm

gives good advice about how to behave around a bear. Their words of wisdom (as of December, 1998) are quoted verbatim in Appendix A.

Our principal protection in the past has been the military-issue Ground Burst Simulators (GBS). A GBS is a small white tube (about 3-cm diameter) containing about an ounce of flash powder. The user pulls a string lanyard and throws the tube. After about ten seconds the GBS starts to whistle, which is meant to simulate a shell going overhead. It whistles for about five seconds and then explodes with a very loud bang. The bear's attention is obtained by the whistle, and the combination of bright flash and loud explosion is very effective in frightening him away. On numerous occasions I have seen GBS get rid of bears, and I have never seen it fail. By comparison, the crack of a rifle going off has, in my experience, never frightened away the bear.

Appreciably less explosive than the GBS is the Thunderflash. This also comes as a small tube similar in size to the GBS, but it is initiated by striking its safety-match-like end on the side of its protective cap. The fuse fizzes for about ten seconds, and then the Thunderflash explodes. It sounds like a loud firecracker, and, although it is not nearly as loud as the GBS, it will usually frighten away a bear.

'Bird Bombs' are another noise maker that we have used with success. The explosive has size (as well as the sound) of a large firecracker. It is placed in the muzzle of a special pistol, and the pistol is loaded with a blank '22' cartridge. When the cartridge is hit by the pistol's hammer it explodes and throws the 'firecracker' several 10's of metres. And, at the same time, it lights a fuze in the explosive, which detonates several seconds after launch. This technique is reasonably effective if the small explosive can be placed fairly close to the bear, but we worry about putting it on his far side, which might case him to flee back towards us. The other disadvantage of the Bird Bomb is that they are slow to load. Each shot requires the finding and loading of both a '22' blank, which is tiny, and an explosive, which is not very large either. All this has to be done with hands that might be numb with the cold, shaking with nerves, or both.

We do take rifles and shotguns with us to use as a final resort - just in case. We prefer the shotgun (with a heavy slug) to the rifle. Our reasoning is that if we have to use a gun, the bear will be quite close, so the accuracy of the rifle is not needed. What we do need is a heavy slug that we hope will stop the bear if he were charging - by breaking a front leg, for example. The problem with using a rifle or shotgun is that the bear will probably not be killed by the first shot - dozens of Arctic stories testify to that. Once the bear is injured he will be maddened, and then he will have to be killed. It is much better to frighten the bear away before the situation degenerates that far. There is, of course, always the possibility that a bear might ambush one of us, and then it will have to be killed. However, so far we have never had to use a gun, and with luck (and access to decent noise makers) we will never have to.

In order for the shotgun to be rapidly accessible in case of an emergency, it is left with the safety off and with no shell in the chamber. To fire it, one simply pumps it and pulls the trigger. We consider this a reasonable compromise between safety and speed of access.

One of our worries has been that a bear could easily walk into the camp without being seen. When we worked in Barrow Strait, where bears were quite numerous, we put a bear-alarm fence around the camp so that they could not come close without announcing their presence. The fence consisted of a number of 1/2-inch or 3/4-inch dowels (*i.e.* wooden sticks) stuck in the snow all round the camp. A single wire containing banana-plug connectors was run from post to post at a height of one or two ft The 'fence posts' were positioned so that there was always one banana plug between each pair of posts. The alarm stayed off as long as the fence was electrically continuous. A bear blundering through the fence would pull a banana plug apart, break the continuity and set off the alarm.

The bear-alarm fence worked reasonably well. As far as we know, every bear that came within the 'compound' tripped the alarm, although we once saw a bear jump the fence on her way back out again. The main problem with the bear-alarm fence was the large number of false alarms. A stiff wind would pull the banana plugs apart, and any Arctic hare coming to investigate would trip the alarm. Moreover, it seemed like the middle of the night was the favourite time for high winds and curious hares. Nonetheless, the feeling of security afforded by the fence outweighed the annoyance of the frequent false alarms.

Bears are quite rare around Alert in the spring; consequently, we have not bothered with the fence when working in that neighbourhood.

At a number of locations (Barrow Strait and Nansen Sound, for example) we built semi-permanent plywood buildings to which we returned many times. When we left at the end of each field trip the buildings had to be made bear-proof . We nailed plywood over all windows and chimney holes, which were quite small anyway, and we nailed plywood over the door. This door covering, however, was usually not enough to deter a bear (Figure 41); he would pull off the plywood with his strong claws. We discovered that nailing steel strips and angle iron over the doors and the edges of the building would stop the bear from getting in. It seemed that they did not like the feel of the steel on their claws, and if there were no wooden edges to grab they would give up. The steel we used was Dexion shelving strips, which are full of holes and, thus, easy to nail. We generally left a hammer on top of the porch for the next human who wanted to get into the building. So far, the bears haven't figured out how to use the hammer.

5.7.6.2 Wolves

Wolves are the next animal that usually comes to mind when safety is considered. Wolves, however, have received very bad press, especially in children's stories, and they are perceived to be very much worse than they really are. We have never seen any sign of aggression or unfriendly behaviour. They have watched us work for hours, and it seemed like they were watching out of curiosity - not hunger (Figure 42). They have run along behind skidoos, and their actions were very dog-like.

This is not to suggest that one should try to become friendly with a wolf. Do not feed them, and do not let down your guard. They have tremendously strong jaws that could take off your hand with a single bite. We have seen them bite cleanly through the handle of a duffle

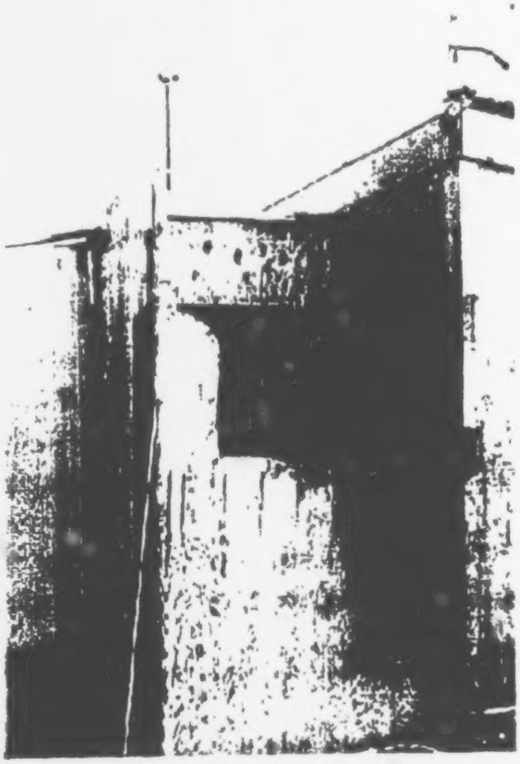

FIGURE 41. A plywood porch that has been ripped apart by a bear

bag, cutting the heavy canvas in two places simultaneously and then spitting out the centre bit.

They are almost impossible to chase away if they do not want to go. At Ward Hunt Island we watched Brendan Donald try to chase a wolf with a skidoo. Rather than run away, the wolf just circled around behind the skidoo, which, in turn, tried to circle behind the wolf. They chased each other in a tight circle for about a minute until Brendan gave up in frustration - embarrassed, perhaps, by the chuckles of everyone else.

Our main problem with wolves is that they will steal anything that is not nailed down. We usually leave our emergency sleeping bags just outside the tent, but this is not wise if there are wolves around. We once had to chase a wolf who was trotting across the pack ice carrying Jim Perkin's duffle bag, which held about thirty pounds of sleeping bag and other clothes. Luckily it was heavy or we would have never caught the wolf even though we were on skidoos. Moreover, he didn't give it back without a show of resistance. He was the one who bit through the handle of the bag and spit it out. And, of course, he urinated on the bag before he stalked off in high dudgeon.

Another time Jim Kennedy got hot shovelling snow, so he took off his parka and left it on the ground. The next time he looked around the parka was being dragged over a snow drift by a wolf. The usual chase ensued, and the usual yellow stain was left on the parka before it was returned.

FIGURE 42. Wolves examining skidoos

Wolves love to play with ropes. They will pull them, bite them through and steal them. Our sleds usually have a couple of ropes attached to them so that they will be handy if they are needed, and these ropes just drag on the snow behind an empty sled. Darryl Gittins was once driving along slowly when he felt a sudden tug on the skidoo. He looked around and saw a wolf who had grabbed one of the trailing ropes in its jaws. The wolf had 'put on the brakes' and was skiing on all four feet as he was dragged by the skidoo. Darryl said the wolf slid for a long way before he gave up.

One year at Nansen Sound we put together an anemometer - made of fiber glass - and wired it ready for installation the next morning. Not knowing there were wolves around, we left it outside for the night, spinning in the wind. When the resident wolf showed up he either took exception to this motion or he thought that anything that moved was edible, but, whatever the reason, he utterly trashed that anemometer.

There have been a few cases of wolves nipping people at Alert and at Mould Bay, but I understand that in every case someone had been feeding the wolves, and the wolf was just hinting that he wanted more. Since rabies is endemic in the Arctic, these nips could truly be dangerous, and so if the wolf can be identified he must be destroyed and tested for rabies. Thus, it is extremely important not to feed the wolves!

In summary, wolves are more dangerous to your belongings than they are to you. There is no reason to be unduly frightened of them, but, on the other hand, they should be treated with a lot of respect and deference. Don't underestimate them, and don't feed them.

5.7.6.3 Foxes

Arctic foxes are small, white, fluffy and cute - except in the summer, when are they black, short-haired, scrawny and homely. Foxes are the sneak-thieves of the Arctic. At Alert, for example, where both foxes and photo opportunities are numerous, one often sees people tossing their gloves on the ground while they grab for their cameras. As one fox poses for the camera (Figure 43) another will flash in from behind and make off with the person's leather gloves. It almost seems planned.

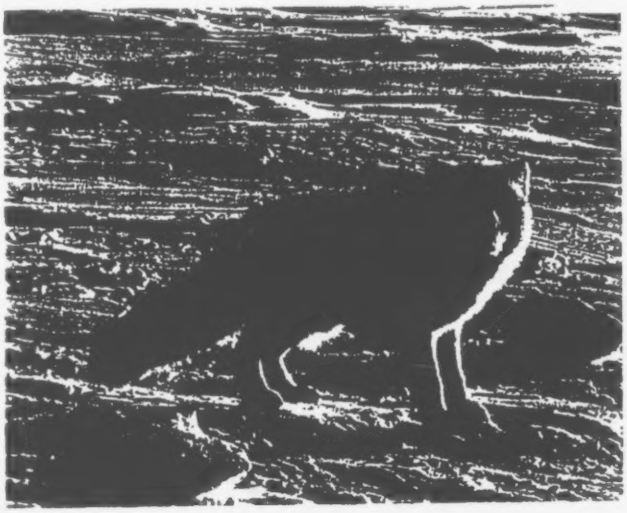

FIGURE 43. Arctic foxes are numerous and quite brazen at Alert. (Photo by Ann Louise Sumner)

At an ice camp the foxes will steal any food they can get. In the spring of 1986 Doug Schneider and I were camped on the Arctic Ocean about 180 km from the nearest point of land when we were disturbed by a scrabbling sound outside the tent. Fearing a bear, we cautiously peered out through an unzipped flap, and we were met by the sight of a fox taking off with one of our steaks. What he was doing 100 miles from shore we never did learn; perhaps he was scavenging in the track of a polar bear. At any rate, he was back twenty minutes later looking for another free lunch, but by that time we had put all our food in a metal box.

This petty theft, however, is not a serious problem. A bigger concern to us is that the foxes like to chew on cables. This means that any installation that has cables running across the ground is very much at risk unless the cables are armoured.

In general, foxes pose little danger to humans except in so far as rabies is endemic in the Arctic. Consequently, all contact with foxes (and all other animals, too) should be avoided.

5.7.7 Snowmobile Accidents

Snowmobiles are extremely useful in what we do. Like automobiles in the south, we would be hard pressed to do without them. However, like automobiles, they can be poorly handled, and accidents can happen. A bad scenario is that of being thrown from a snowmobile going at a high speed. The obvious solution, of course, is not to go too fast, and this is generally not hard to enforce. In our experience, people very seldom speed past their capabilities for the simple reason that the high speed is quite frightening.

The accidents in which someone has been hurt have occurred at fairly low speeds. During white-out conditions, for example, it is sometimes not possible to see a snow drift. We have had an instance when someone has hit a snow drift at an angle and has been thrown off in the path of the heavy sled behind him. He was not going fast but was quite badly hurt. (This was a fault in the design of the sled hitch, and has since been remedied.) I drove off a cliff once during a whiteout when I could not see the details of the snow in front of me. Luckily, I landed on very soft snow and was not injured at all. However, the accident made it clear to me (and hopefully to others) that a whiteout can be a very dangerous condition.

5.7.8 Ice Breakup

Sea ice within the channels of the archipelago is quite stable in the spring, and the probability of it moving or breaking up while we are occupying it is extremely small. However, in the Arctic Ocean proper, the ice at a camp often moves, and sometimes it opens up. Open cracks are not an immediate danger, although they can interfere with the comings and goings of aircraft, and the breakup of an airstrip might cause the premature closing of the camp. Only once did the ice do actual damage to our camp. In 1990 the ice right at the camp was crushed by heavy pressure (Figure 44), and the tents were slowly run down by the advancing pressure ridge. We had to call for an emergency evacuation. The weather had been foul and unflyable for days, but luckily, just when we needed the helicopter, the weather improved substantially. When the helicopter arrived we were able to rescue most of the equipment, but we did lose some tents. Two Octagons, a Hurritent, a plywood shelter, a skidoo and a sled were all engulfed during the next day or so by the ridge of ice that marched right over the camp.

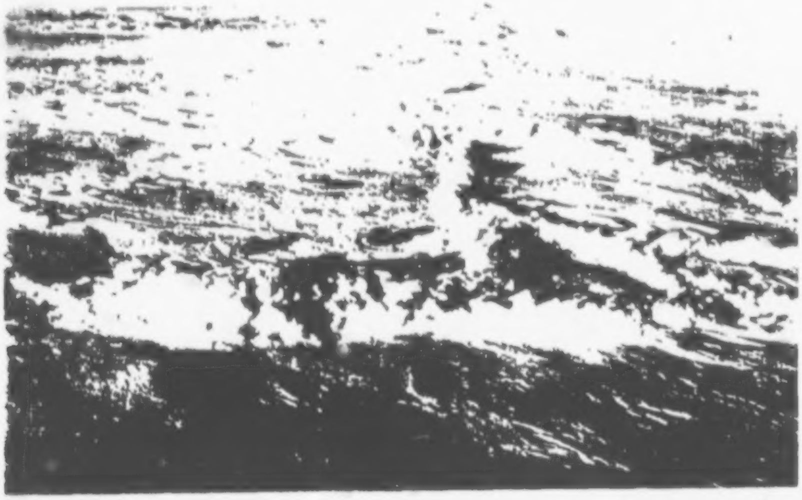

FIGURE 44. The slowly moving ice ridge is in the process of over-running the camp

We were quite disturbed afterward by the thought of what might have happened had the helicopter not been able to come, and we developed an emergency sled to be used if the ice ever broke up under us again. A commercial 'Thule' car-top carrier was fitted out with skis (turned up at both ends) and filled with a selection of emergency equipment. A small tent, a cook-stove, some fuel, food and a couple of sleeping bags are part of the gear stored in this box. It is sufficient to give three people food and shelter for about a week. Appendix B gives a listing of the contents of the sled. We were careful to ensure that the completed sled was light enough that two people could pull it over rough ice. Rope handles were attached at both ends of the sled so that it could be pulled in either direction or so that someone could bring up the rear and prevent the sled from over-running the person out front.

6.0 Making Holes Through the Ice

6.1 Introduction

Installing equipment in the ocean and getting it back again is made particularly difficult in the Arctic because of the ice cover. Much imagination and ingenuity has been exercised in developing ways of making holes through the ice, and, as one would expect, some are more practical than others. Mellor[17] gives a review of the techniques and equipment that were in use in 1986, and he discusses a number of ideas that perhaps have potential. He also provides a good bibliography. The proceedings[18] of an Ice-Drilling Workshop also describes some state-of-the-art techniques.

This section describes the techniques that we are familiar with, and it gives our estimate of their strengths and weaknesses.

Before discussing hole drilling techniques, however, we must emphasize something that is as important as it is obvious: small holes are easier to drill than large holes. All equipment that is to be put through the ice should be designed to go down a hole that is as small as possible. This design feature is not something that is usually applied to equipment that will be lowered from a ship, and it is very hard for a non-Arctic designer to realize its importance. For example, a small appendage on a piece of equipment might force the operators to drill a twelve-inch hole rather than a four-inch hole. This will take much more time, energy and equipment. Moreover, it will increase the probability of failure. It is good practice to warn the design engineer that he will have to drill the holes for his equipment.

6.2 Early Techniques

6.2.1 Chainsaws

One of the early ways of making a large hole through the ice was to use a chainsaw. The only time that I saw this done, the ice was fairly thin (about 5 ft) and a seven-foot-long chainsaw blade was used. The job was quite time consuming, and the operator, who was sheathed in a rubber suit, got extremely wet since the blade pulled up a steady stream of water.

The technique of making holes through thick ice with reasonably sized chainsaws has gone out of fashion. I was never involved with making a hole this way, but the technique was described to me by Harold Sersen, and it is worth repeating for its historical interest.

First of all, the thickness of the ice is measured by drilling a hole with an auger. The knowledge of this thickness is later used by the workers to gauge how close they are getting to the bottom of the ice.

Most Arctic ice is much too thick to be cut by a single pass of a chainsaw, and so multiple cuts are necessary. A rectangle is marked off on the ice and a series of chain-saw cuts are made in a chequer-board fashion across the rectangle. A heavy ice chisel or an axe, or both, is then used to break out the individual blocks of ice. Once all the blocks have been removed and the ice made reasonably level, a second series of cuts is made, thus pushing the hole deeper. Because the saw blade of the chainsaw can not get right to the edge of the hole, the second rectangle is slightly smaller than the first. Subsequent layers are, of course, even smaller, and for this reason the original rectangle has to be somewhat bigger than the desired ice hole.

The job of breaking the ice blocks and throwing them out of a deep hole is brutal, and breathing the chain-saw motor fumes at the bottom of the hole is not much fun either. It is quite obvious why this technique has fallen out of favour.

Because of the original hole that had been drilled, the workers know how close they are getting to the bottom of the ice. They take great care not to break into the water prematurely as they thin the remaining amount of ice. Once the ocean is breached, the hole rapidly fills with water as the workers scramble out. The rest of the ice (hopefully thin) has to be chopped out with a long-handled ice chisel wielded (in the blind) from the surface.

6.2.2 Explosives

Another nearly obsolete method of making a large hole through the ice is to use explosives. As far as I know, this was used only in annual ice, which has a thickness of at most six feet.

The required hole, whether round or square, is marked out on the ice, and at its centre a small hole (three or four inches in diameter) is drilled through to the water below. This hole is ultimately used to hold the explosive, but its first use is to determine the thickness of the ice. Then a series of small holes (four-inch diameter, say) are drilled as closely together as possible around the perimeter of the planned hole. This is usually done by power-auger since there are so many holes to be drilled. The holes are stopped short of the bottom of the ice so that they do not fill with water. They are left dry so that the shock wave from the explosive will reflect at the air interface and not pass through the water to the solid ice on the 'outside' of the hole. As well as protecting the 'outside' ice, the air interface causes the 'inside' ice to be further shattered by the reflecting shock wave. A string of one-pound charges is then wired-up (as shown in Figure 45) and lowered down the centre hole (the wet one). Generally, one charge is placed one third of the way down the hole; another is placed two thirds of the way down and a third is placed two or three ft below the bottom of the ice. The first two charges are to shatter the ice in the hole, and the third charge is to blow the ice up and out of the hole. The ice remaining in the hole is then shovelled out. This is the theory. In my experience the ice was, indeed, blown straight out of the hole, but most of it fell straight back in. Even the smallest hole contained over a ton of ice that had to be removed and then shifted far enough away so that a tent could be erected over the hole.

FIGURE 45. A string of charges being lowered down the centre hole. Two 1-lb charges can be seen. Also, note the holes drilled around the centre hole.

The amount of explosive described above was usually quite adequate. Most of the ice was broken into small enough pieces by the explosion that even the large chunks could be lifted out of the hole by two men with shovels. Any really large pieces are split with an ice chisel. In fact, the charge was often just a little too powerful. It would sometimes break up the surface of the ice just outside the hole, and the sloping ice would make working around the hole a bit precarious.

6.2.3 Axes

Although the axe is seldom used to make ice holes, it is included in this list for completeness.

If the ice is less than a foot thick, an axe can knock a hole through it very quickly. After all, prairie farmers regularly chopped holes in the river or pond ice so that their cattle could drink. The problem, of course, is that if the ice is that thin, then it is too weak to hold an aircraft.)

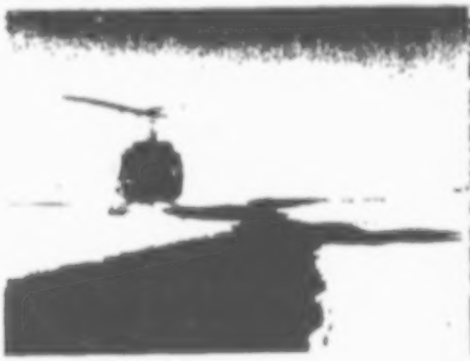

FIGURE 46. The helicopter is sitting on ice that is 15-to 20-ft thick (as estimated from the freeboard). The neighbouring ice is a newly frozen lead.

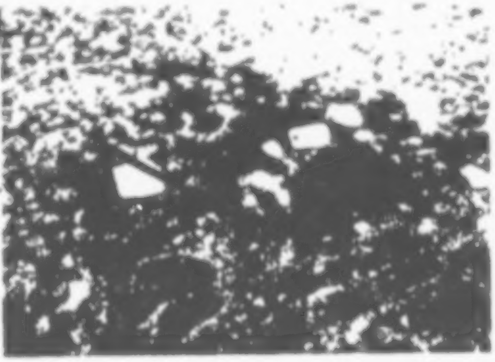

FIGURE 47. This hole was chopped through the 5-in-thick ice in about a minute with the hand axe.

The technique can be useful, however, if a helicopter can land on thick ice that is right next to a thin refrozen lead, as is shown in Figure 46. The hole in Figure 47 was the result of some Arctic improvisation. We were miles away from camp on a sound-propagation run, and the gasoline-powered drill refused to start. We took off from the aborted hole and hunted around for a very thin lead beside some heavy ice, and we chopped our way through the ice with the helicopter's emergency axe (shown beside the hole).

6.3 Augers

6.3.1 Hand Augers

We now come to techniques that we use regularly. Our most popular hand-powered drills are made by Finbore, a Finnish company. A Finbore drill consists of a cutting head at the bottom end, a crank at the top end and any number of two-foot-long auger flights in between. The Finbore drills come in several different diameters. Our standard sizes have been 4-in, 6-in and 8-in diameters, with the 4- and 8-in sizes being used the most.

The unique aspect of Finbore drills is the extreme sharpness of the cutting head. They are literally razor-sharp and they cut ice very rapidly. For example, a four-inch-diameter hole can be drilled through six feet of ice in less than a minute. The cost of this speed is that the cutting edge of the drill must be carefully guarded. The slightest tap of another piece of steel on the cutting edge will render it useless even though there is no visible damage. The drill will just not cut. Since it is practically impossible to grind, hone or strop an adequate edge on the cutter, the only solution is to throw away the damaged head and replace it with a new one. It is important to convince all newcomers of the drill's delicacy, and this is uphill work. A new person will nod understandingly as he is told how to baby the drill. Then, after successfully drilling his first hole, he will promptly forget and toss the naked drill over toward the nearest shovel. The old-timers holler at him, of course.

Associated with a razor-sharp cutting edge is a technique called 'turning the edge'. It is possible to turn the extremely thin cutting edge up or down slightly by carefully drawing a blunt piece of steel (a screwdriver shaft, for example) across the bottom or the top of the cutting edge. One gentle stroke will push the almost invisible feather edge up or down. No difference can be seen, of course, and the uninitiated observer will look at you with a trace of fear in his eyes, but the results are indeed remarkable. If the ice is cold, fresh and hard, and if the auger has been cutting slowly or not at all, turning the edge down will make it cut much more aggressively, and the ice chips will come boiling out of the hole. On the other hand, if the ice is warm, saline and soft, the auger may be almost impossible to turn because of the size of the chips that are being torn out of the ice. In that case, turning the edge up will make the auger less aggressive and easier to operate.

We usually join the 2-ft auger flights in pairs and store them as 4-ft flights. Separating all the 2-ft sections represents needless work, and a 6-ft flight is so long that an operator needs a stepladder to get started. The usual procedure is to drill down until the top of the flight is almost at ice level. Then the drill handle is unpinned, a new 4-ft section is added to the flight that is already in the ice, the handle is reconnected and the drilling is restarted.

Something as seemingly simple as bolting or pinning the sections together took us a long time to get right. The shaft of one drill section fits into the socket of the next one in such a way that the helical flights line up with and abut one another. The adjoining flights help transmit the torque from one section to the next - except when the drill is cranked backwards. When the two sections are correctly fitted together, crosswise holes line up so that a bolt can be pushed through the two sections, thus fastening them together. For this job we originally used quarter-inch bolts and nuts, but they were time consuming to put together and undo with wrenches. Remember that this had to be done at -35° with gloves or mitts on, and, if one of the tiny bolts or nuts fell down the hole, the hole had to be abandoned in order to protect the delicate cutting edge of the drill. A new hole had to be started. We soon gave up on bolts and nuts and switched to pins that were held in place with cotter pins. Although this was better, the arrangement was still cumbersome since the cotter pins had to be bent and then straightened every time they were put in and taken out. Moreover, they were easy to lose in the snow or down the hole. Also, we found it hard to line up the holes in the two drill sections so that the pin would go through. Finally, to add insult to injury, the cotter pins would sometimes break off in the hole, and the main pin would work its way out of the shaft. This would allow the lower sections of drill to fall to the bottom of the ocean once the drill bit was through the ice.

We finally discovered the so-called 'farmer's pins', which have a built-in spring-loaded keeper (Figure 48). This one-piece pin reliably held the sections together and was large enough not to get lost in the snow. Also, we tapered the ends of these pins so that the holes in the shafts would not have to be lined up perfectly before the pin could be inserted. Once the tapered pin was started, a few sharp blows with the back of a wrench would force the holes into line. We also learned to fill up the ice hole with ice chips before starting to work with loose pins. It is almost impossible to lose a pin (or anything else) down a hole that is overflowing with ice chips.

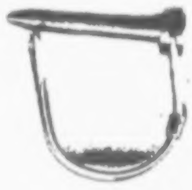

FIGURE 48. A 'Farmer's pin'.

The next problem arises when the drill breaks through into the water below. The seawater immediately rushes up and soaks all the chips surrounding the auger. The water is at its freezing point, and most of the ice chips are well below freezing. Moreover, the walls of the ice hole near the surface are still very cold. Consequently, this enormous 'slurpy' will begin to freeze quite quickly and, unless something is done immediately, the drill will get stuck down the hole. To make matters worse, the porridge of sodden chips is very heavy and viscous, and removing either the ice or the drill is quite difficult, especially if the hole is deep or its diameter is large. If the hole is relatively small, an up-and-down pumping action will bring the slush to the surface (Figure 49). In this game, one has to start with short strokes.

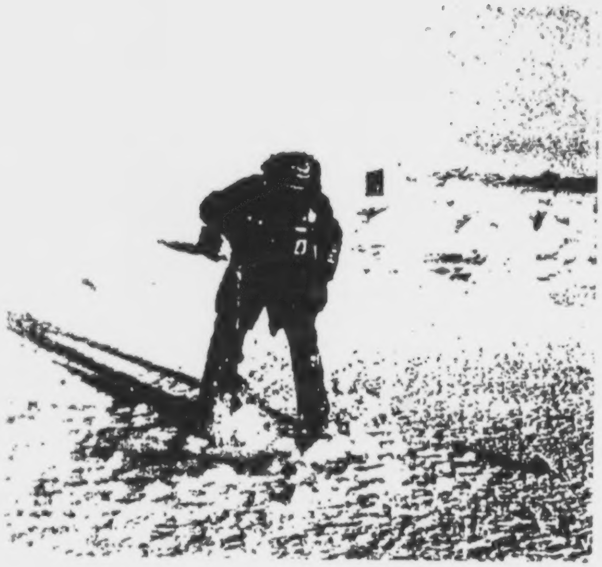

FIGURE 49. Drilling a four-inch hole through thin ice with a Finbore drill Here, Dave Baade is 'pumping' the chips onto the surface

Once the action becomes easy, and if one's timing is good, a lot of water can be quickly flushed onto the surface bringing the chips with it. If one has carefully cleared the chips away as the hole was being drilled, the water will run back down the hole taking a lot of the chips with it. It is better to resist this desire for good housekeeping and just let the ice pile up as a cone around the hole (Figure 50). The cone dams the water on the surface and the chips are prevented from flushing back down the hole. This technique clears the hole much

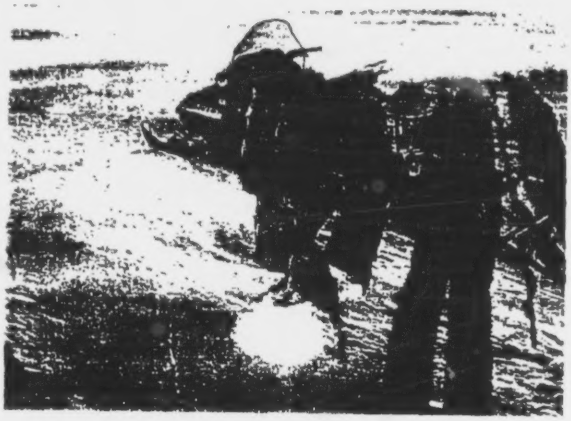

FIGURE 50. The author drilling a 4-inch hole. Note how the chips are allowed to pile up. This keeps the water from flowing back into the hole once the hole has been flushed out.

more quickly. The flooded ice surface does not remain wet very long since the water either runs away, gets soaked up by the snow or freezes.

Sometimes, when large masses of chips are involved, two people are required to start the pumping action. Occasionally, not even two people are enough to budge the mass of ice and water. In those instances the drill is quickly backed out of the hole three or four ft (by cranking it backwards), and the pumping is attempted once again. Eventually it comes, and once the water starts to flow onto the surface, the danger of entrapment is over.

The next step in the process is to remove the drill stem. If the hole is less than 12 or 16 ft deep, the entire drill stem can be pulled up at once and laid on the ice. The 4-ft sections must be quickly unpinned and pulled apart or they will freeze together. When the temperature is -35° and a wind is blowing, one has only 15 to 30 seconds for this. If the hole is 20 or 30 ft deep, the drill lengths must be separated while the stem is still standing in the hole. Usually, about 12 ft at a time is pulled up, disconnected and separated into 4-ft sections. Someone else hangs on to the sections remaining in the ice hole.

The final step in dismantling the drill is to clean the flights, especially the ends of the shaft. If an end is dropped into the snow while the shaft is still wet, it will get covered with wet snow, which will soon freeze and prevent the reuse of the drill. Even if the drill is just wet and not snowy, the resulting ice in the end socket or on the shaft will substantially reduce the clearance. If an engine is running, which is the case if a power head is being used, the drill ends can be placed in the engine exhaust until the ice melts and the shaft is dry. If neither an engine nor any other heater is handy, then one must be extremely careful not to get the ends covered with snow. A squirt bottle full of alcohol and a little oil will provide some assistance in getting two icy ends to fit together the next time the drill is used. As a desperate measure, a snowmobile's exhaust system can usually be tapped in order to get access to the hot exhaust. After a day's drilling, it is good practice to bring all the drill stems into a warm tent, stack them behind the stove and let them dry out thoroughly. A little light oil (*e.g.*, WD-40) on both ends will help prevent rust.

Before assuming that the ice hole is complete, one must check that the hole is, indeed, through to the ocean below. First of all, when the chips are being pumped out, the drill stem should be pushed down as far as possible to make sure that the drill has fully penetrated the bottom of the ice and has not just cracked a hole large enough to let the water in. Secondly, if the hole is being drilled in an area of rough ice, there is a possibility that the ice is rafted and that a second layer of ice is lurking a few feet below the first layer. It is very embarrassing to drop a SUS charge (an explosive), for example, onto a layer of rafted ice. If rafting is suspected, the driller should tie a string to a weight and lower it 30 or 40 ft below the ice surface. If the ice is, in fact, rafted, the hole should probably be abandoned in favour of a new location.

6.3.2 Powered Augers

Human-powered drills have several advantages. They are light and they are easy to set up and take apart. Moreover, the power supply is reliable (at least in spirit), whereas gasoline engines are sometimes very hard to start in the cold. Once the volume of the hole becomes large, however, the advantage of mechanical power outweighs the disadvantages of hauling extra equipment and having to start an engine. An eight-inch auger drilled into the ice more than 8 or 10 ft is very difficult to turn by hand because of the great mass of ice chips. We once hand-drilled an eight-inch hole through ice that was 33 ft thick, but that was an all-day affair, and a special chip scoop had to be jury-rigged on the spot. We would much rather use a power drill for ice this thick.

We now use gasoline (or diesel) power for these large holes and even for small holes if there are a lot of them to be drilled.

Our so-called 'power heads' for turning the drill come in two forms. The first uses a half-inch electric drill to turn the auger. The electric power for this drill is produced by a separate motor-generator. The other type of power head actually contains a small gasoline engine and a gearbox, which reduces the engine's rotational speed to something appropriate for an ice auger. The unit we use, which is made by Stihl, is mounted on a frame that has four handles. It is operated by two people who support the power head and supply the torque for the cutting (Figure 51). We have built special adapters to couple these power heads to the various types of drill that we use.

Although we have adapted the Finbore drills to be used with the power heads, these drills tend to be a little lightweight for the amount of torque that the power heads can apply. Much more solidly built drills are available for use with power heads. They are heavier to handle, but they do take the rougher handling without bending the stems or stretching the boltholes. In particular, our 10-in and 12-in drills are quite tough. Also, their cutting heads are much more primitive and rugged than the Finbore cutting heads. The cutting edge is composed of serrated teeth that scrape the ice, rather than slice it. They are neither as sharp nor as delicate as the razor edges of the Finbores. Even if they are quite dull they will still cut, albeit slowly. Moreover, they can be sharpened with a file. Only the availability of lots of power makes the use of this type of cutter possible.

One of the advantages of the power drills is their high rotational speed (at least compared with human-powered drills). The constant high speed brings the ice chips to the surface very effectively, and the reduced quantity of chips lessens the sudden load on the drill when the chips get wet. Also, once the drill has penetrated into the water below the ice, its rapid rotation pumps lots of water onto the surface and thoroughly flushes the hole free of chips. No up and down pumping action is required.

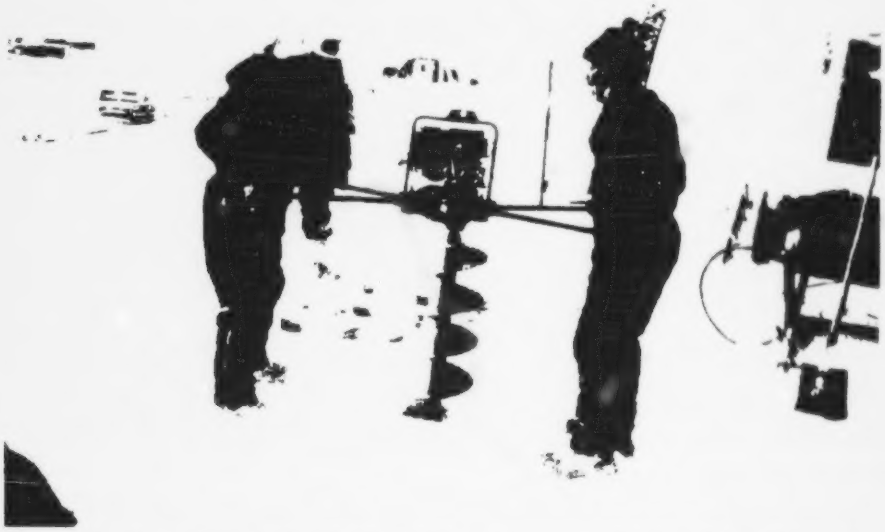

FIGURE 51. Tudor Davies and Jim Perkins drilling a ten-inch hole with a Stihl power-head.

A major disadvantage of the power drill is the weight of the power head plus drill stem. The strain on the two people supporting the drill is not particularly high while they are actually drilling since they let the ice take most of the weight. However, when the drill breaks through the ice into the water below they are suddenly forced to take the whole load. Even more importantly, the ice chips that remain in the hole turn into a thick soup, and the rapidly turning auger tries to screw itself and everything attached to it down into the ocean. Sometimes heroic measures are needed to get the drill back out.

Because of the sore backs and crushed knuckles occasioned by these power drills, a 'sky hook' was developed to take the weight. This support took the form of a tripod and a block and tackle. The tripod legs are 30 ft long, each being made of three separate 10-ft lengths of 3-in aluminum tubing (having 1/16 -inch wall thickness). The top of each leg is fitted with an 'eye', and the three eyes are lashed together with rope to form the tripod.

A block and tackle that has two sheaves top and bottom is roped to the top of the tripod, and its lower end supports the power head. This tripod takes about twenty minutes to put together, and three or four people are required to stand it up (Figure 52).

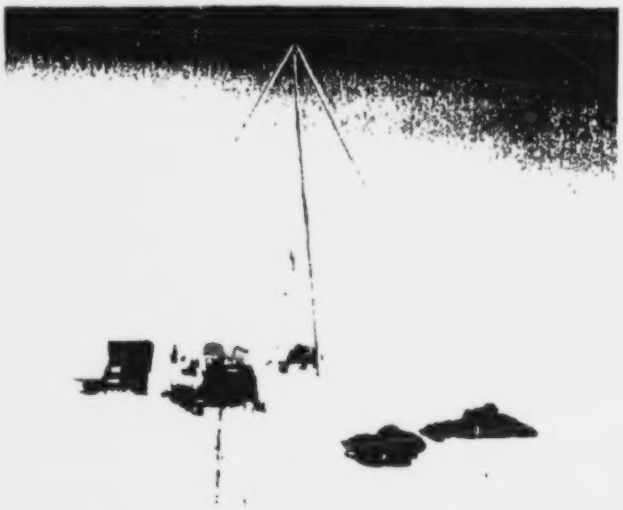

FIGURE 52. A tripod assisting with hole-drilling. One operator (bent over the hole) is attaching another 4-ft drill stem while the tripod holds the power head out of the way. (The other operator is taking the picture.)

The block and tackle has a mechanical advantage of four, and the person in charge of it can easily hold the weight of the drill plus drill stems. He sets the rate at which the drill penetrates the ice. A rope cleat is fastened to each tripod leg so that there is always one within easy reach of the operator, and this cleat is used for extra restraint when the drill is about to break into the water. (One can usually tell by the sound and feel of the drill when it is about to break through.) A second person (sometimes two) controls the drill head and provides the necessary torque for the drilling. Once the ocean is breached and all the chips are flushed out of the hole, the block and tackle can quite easily lift the drill head and at least 20 ft of stems out of the ice. If the auger is longer than this, the stem will have to be taken apart while it is still in the ice. Once it is free of the hole, the drill stem is lowered onto the ice and quickly taken apart (Figure 53). If another hole is to be drilled, the tripod is pushed over onto the ice and dragged away to the new spot. In this way we regularly drilled 8-in or10-in holes through 20-ft-thick ice and sometimes through 30-ft-thick ice.

Although the tripod works very well, it has its disadvantages. It takes quite a while to put together and set up, and it really needs at least two people - preferably three or more- to stand it up. In hopes of circumventing these difficulties, we developed an alternative sky hook that we called the monopod (see Figure 54). It is just stuck in a slanted four-inch hole in the ice, and it can be installed by a single person. Its disadvantage is that it does not have the height of the tripod, and since this is a fairly major disadvantage, the monopod seldom gets used.

Before leaving a discussion of mechanical drills, there is one other phenomenon that should be mentioned. Very occasionally a drill that has just penetrated into the water will be pushed back out the hole by the pressure of the water below. This seems to happen only to drills whose cutters have a faceplate that is almost a complete circle. In other words, the cutter is attached to plate that approximates a piston. If the drill is driven up by water pressure, it comes with a rush, so it is important not to have one's face over it.

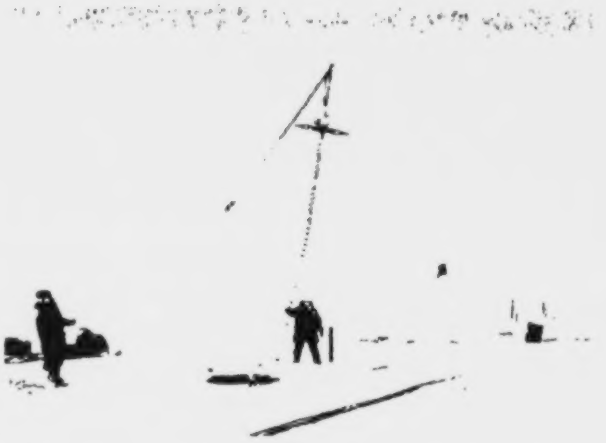

FIGURE 53. The Stihl power-head and the complete drill stem being pulled away from the hole. At this point the four-ft sections will be quickly separated from each other

The only injury that I can recall is a smack on an elbow that John Ozard received by a rising power-head. As an injury, it was fairly minor, although I understand that the elbow was sore for a while. To my knowledge, the most impressive example of this expulsion phenomenon was experienced by Harold Sersen when he was taking ice cores through the Ward Hunt Ice Shelf. The ice was about 40 metres thick, and when they broke through into the water below, the drill stem rose magnificently into the air and laid itself across the wing of a Twin Otter that was parked nearby. Luckily, no damage was done.

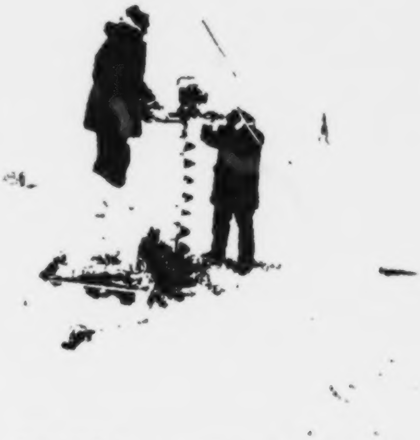

FIGURE 54. A monopod being used to support the 10-inch drill

6.4 Making Holes with Hot-Water Drills:

6.4.1 General Principles

We first designed our hot-water drills to make holes through very thick ice - the 45-m-thick ice of the Ward Hunt Ice Shelf. However, we have used them most for cutting large holes in much thinner ice. Also, we find this type of drill to be very useful for recovering equipment that is suspended by a frozen-in cable. Occasionally, too, we use it to rescue mechanical augers that have become stuck in the ice.

The principle of a hot-water drill is simplicity itself. One heats up water, pumps it into a hole in the ice, recovers the cooler water and then runs it back through the heater. In practice, however, we have put a lot of thought and effort into making a system that is simple, rugged, reliable and easy to use. The hot-water drill is no longer an experimental piece of equipment; it has become a tool that we take for granted.

Before discussing the drill itself, however, we should look at the principles of operation and at some of the physical units involved. First of all, the drill works solely by melting the ice; there is no attempt to cut or abrade the ice with a high-pressure jet. Secondly, all the heat that the drill puts into the water goes into melting ice in the hole. Some people will argue that the returning water is still warm and, therefore, not all of the heat has been lost, but one can usually make them see the flaw in their reasoning. Thus, once the heat output of a drill has been measured, it is easy to calculate the rate at which a hole can be drilled. Finally, the temperature of the hot water is of only peripheral interest; the all-important parameter is the power (heat per unit time) that is put into the water. Strange as it may seem, some designers brag about how hot the water gets without ever quoting its flow-rate.

The science and technology of heat is very old, and both the SI and the English systems of units are firmly entrenched. Calculations involve such units as calories, joules, British Thermal Units (BTU's), kilowatt-hours, degrees Celsius, degrees Fahrenheit, pounds, kilograms, Imperial gallons, US gallons, litres, etc., etc. One must be flexible.

Reference books, such as the Handbook of Chemistry and Physics, tell us that the heat content of most liquid fuels, such as diesel fuel or kerosene, is about 19,000 BTU per pound, and they also quote the density of these liquids is roughly 7.5 lb/gal(US). The fuel nozzles in the burners we use are rated in US gallons per hour. Using all this, one can estimate the heat produced by the fuel. For example, if we are using a 3-gal/hr nozzle, the heat of combustion is approximately 3 x 7.5 x 19,000 = 428,000 BTU/hr, some of which goes into the water, the rest going up the chimney.

The specific heat of water is 1 cal/(gm °C), and it is also 1 BTU/(lb °F). From this easily remembered relationship one can compute that 1 BTU equals 253 calories. And, since 1 calorie equals 4.18 joules, 1 BTU equals 1056 joules and 1 BTU/hr = 0.293 W.

We use the specific heat of water to measure the output of the hot-water heater. The procedure is to run either tap water or seawater through the heater without recycling it. After the output temperature has come to a steady-state, the water's temperature-rise and its flow-rate are measured. This can be used to calculate the power put into the water. Typically, with the above heat input of 428,000 BTU/hr, between 250,000 and 300,000 BTU/hr (73 to 88 kW) would be put into the water, and, as was said before, all of this is available for melting ice.

To compute how fast this will melt the ice, one uses the fact that the latent heat of ice is 80 calories per gram or 144 BTU/lb (approximately true for seawater ice). In practice, about 10 to 15% should be added to this heat of fusion since the cold ice must first be heated to its melting point. As an example, these values predict that a heater with an output of 250,000 BTU/hr would take about 4.4 minutes to melt a 6-in-diameter hole through 10 ft of ice, which is in reasonable agreement with our experience.

6.4.2 DREP's Hot-Water Drill - the Present Model

The present incarnation of the DREP hot-water drill (Figure 55) uses an ordinary furnace burner (Riello Mectron 15 M) to produce the heat. The flame is directed into a burning chamber, and from there the hot air passes through a copper heat exchanger (Alaskan Copper model from Alaskan Copper and Brass Co., Seattle, Washington) and up a short chimney. Water is circulated through the heat exchanger by a gear pump driven by a ½ HP electric motor. As the hot water comes out of the heat exchanger, it is directed in one of two directions by a Y-valve (Figure 56). One route leads the water into a 10-gallon tank built right into the framework of the hot-water drill. This tank is used for melting snow and for storing a reserve of hot water for filling the long hoses, priming the pump, etc. The other route feeds the water to the long hoses and drill fittings that actually do the hole-melting.

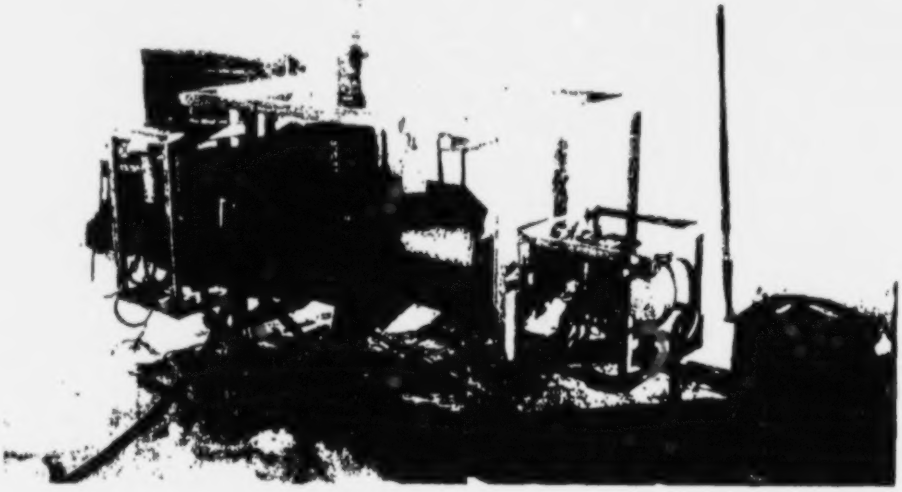

FIGURE 55. Hot water drill. The burner is on the right. To its left is the combustion chamber, and left of that is the heat exchanger Above the combustion chamber is the water tank

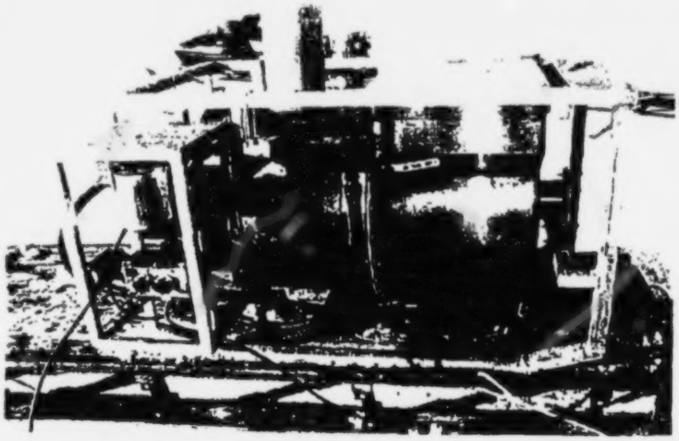

FIGURE 56. Detail of the hot-water drill showing the pump unit hung on the side of the main frame. The two red 'panic' buttons can be seen at lower left. The Y-valve (yellow handle) directing the water in one of two directions is in the centre of the figure.

Just as the output water can be sent in either of two directions, the pickup water can be drawn from either of two sources. One possible feed is from the local storage tank described above, and the other is from the ice hole in progress. A second Y-valve switches smoothly from one to the other. One or both of the two feeds is open at all times.

In practice, the drill is started by circulating the water into and out of the small tank - the 'small circuit', as we call it. This allows us to top up our water tank with melted snow and get everything warm and working before we commit any of the precious water to a drilling process. Once the long hoses are filled and everything is ready, the hole can be started. It is especially important to ensure that the suction hose be full of water and that it is actually delivering water to the pump. Gear pumps are particularly sensitive to air bubbles in the feed line, and, if the flow does stop, the water in the heat exchanger will boil in much less than a minute.

The outlet hose is a ¾-inch GATES 3B multipurpose hose whose working temperature range is -40° to 250 F. It is quite flexible even at the lowest temperatures, although its flexibility does improve when it is warmed up. Its internal diameter is ¾ inch, which gives it a good water-carrying capacity. The suction hose is ¾-inch GATES U2 suction hose, seamless and reinforced with interwoven helix wire. It is specified to a vacuum of 25 inches of mercury (or 28 ft of water). All hose connections are made with 'quick connects' which allows the whole system to be dismantled quickly and drained if anything goes wrong. The 'quick connects' are fitted with #212 Silicone O-rings, which are adequately flexible in the cold. The ordinary neoprene O-rings are much too hard and stiff in the cold. (They are too stiff even at Cape Canaveral temperatures.)

In principle, the hot-water heater is simple and straightforward, and, in fact, we worked very hard to keep it simple. However, there were a great many ways for trouble to arise, and many of the problems occurred because it is hard to keep water liquid when the surrounding temperature is in the neighbourhood of -40°. The drill was subjected to modifications - some major, some minor - every year for quite a number of years. The history of the problems and their cures might be of interest to others trying to design hot-water drills.

6.4.3 Development of the DREP Hot-Water Drill - Trials and Tribulations

The first heat exchanger that we used was a steam-jenny, a convoluted coil of iron piping designed to produce high-pressure steam for cleaning automobile engines. Its principal advantage was that it was easy to obtain. This, however, was soon outweighed by its disadvantages. The jenny was made of ½-in steel piping, and it was heavy. The heat conductivity of the steel was poor, and so its efficiency was low. Its most damning characteristic, however, was that the convolution of its pipes made it impossible to drain. No matter how it was tipped and turned, appreciable amounts of water were left in the tubes. Therefore, we made no attempt to drain it by tipping it; rather, we just boiled it dry, generally letting the pipes get quite hot to make sure there was no water left. Eventually, however, we were not sufficiently diligent, and we left some water in a cooler extremity of the piping. The next morning we found that a section of the coil was full of ice and had split. We were on the Ward Hunt Ice Shelf at the northern extremity of Canada, thousands of miles away from spares, and the success of the field trip depended on drilling a hole through the 45-m-thick Shelf. Luckily, the split was near one end of the piping, and we were able to hacksaw it off. With some difficulty we filed a pipe thread onto the new end, jury-rigged some new plumbing and continued with the drilling. The primitive pipe thread did not even leak.

Problems with the steam-jenny on the Ward Hunt Shelf were still not over, however. As a result of some building construction, there was a dusting of sawdust on the snow, and some of this got into the drilling system, where it seriously reduced the water's flow rate and increased the backpressure. This blockage was, in part, blamed on the sharp turns in the iron piping where the sawdust was probably trapped. As a consequence of the backpressure on the water pump, we burned out two electric motors and then had to jury-rig a small gasoline engine to the pump. In the end we managed to make an adequate hole through the 45-m-thick ice shelf, but we went home with a long list of things to change.

The next heat exchanger was a home-made version of a fire-tube boiler. The hot air (or fire) was directed through about a dozen straight small pipes (1/2-in steel plumbing), all of which were enclosed by one large pipe. Water filled the space between the small pipes and the large outer pipe. This unit was definitely free-flowing and easy to drain. We had gone overboard in that direction. When it came to delivering hot water it worked adequately, but it had the disadvantages of being very heavy and thermally inefficient.

The heat exchanger that we now use, and with which we are quite happy, is a commercial unit (Alaskan Copper and Brass). It is a coil made of finned copper tubing. The coil drains well because the coil is wound in one direction; there are no pipes running backwards and forwards to trap the water. It drains completely when it is tipped up on end. The circular fins, which are attached to the copper tubing, increase the surface area exposed to the hot air. This increases the rate of heat transfer and improves the efficiency. The hot air passes from the inside to the outside of the coil, and from there it is collected and passed upwards to a short chimney. The chimney is there not so much to produce a draft but to get the exhaust gasses above the noses of the operators. Before going to the copper heat exchanger, we tried using a mild steel exchanger on the basis that it was stronger and tougher than copper. Its downfall was the fact that the fins could not conduct the heat into the tube fast enough, with the result that the fins exposed to the hot flame burned away. The copper fins, with their higher conductivity, do not burn.

Next to the heat exchanger, the unit that gave the most trouble was the burner. After trying several models, we settled on the Riello 10M furnace burner, but even it had to be extensively modified for use in the very cold. First, all the safety mechanisms had to be removed; they simply did not work in the cold. Next, the fuel delivery system had to be modified.

First of all, note that we use a self-priming (two-hose) fuel system; life is just too short to deal with the priming problems of a single-hose system. Originally, however, when the fuel pump was turned off to extinguish the flame, fuel would continue to leak through the nozzle into the burn chamber and cause dirty flare-ups. We eliminated this oil-drip by putting a small valve in the line leading from the fuel by-pass to the nozzle. Now when we wish to turn off the burner, we just close this valve, and this immediately shuts off all the fuel to the nozzle. All the fuel, rather than just some of it, is now diverted through the by-pass and back to the fuel barrel. Using this technique, we can leave the fuel pump running all the time. This keeps the fuel pressure up so that the burner is always ready to be used, and it also removes the necessity of turning the fuel pump on and off, which is hard on the motor at very low temperatures.

The spark for igniting the spray of fuel is provided by a high-voltage transformer driving current across a spark gap. In a house furnace the arc runs constantly so that if the fire should go out momentarily it will immediately reignite. However, for some still-undetermined reason the transformers we used had a short lifetime in the cold. If we left them on continuously, they would burn out. We cured this simply by leaving the transformer off most of the time. Now it is turned on only long enough to ignite the spray of fuel. The switch is spring-loaded, so that when it is released the spark goes off. The transformer seems to appreciate this low duty cycle and has never again given problems.

Associated with the burner is the combustion chamber, which is the region in which the burning takes place. The volume of this chamber must be large enough so that the combustion is complete before the hot air begins to pass through the heat exchanger. If the burning gasses should hit the heat exchanger before all the fuel is burned, the cold surfaces of the exchanger would immediately extinguish the flame, and the remainder of the fuel would pass up the chimney (as carbon monoxide or black smoke) or would deposit itself as soot on the fins of the heat exchanger.

The water pump and its motor also gave their share of problems. After we burned out a couple of motors, we made sure we always used heavy duty, capacitor-start ½-HP motors. We also used the best quality brass gear pumps. The main problem with the gear pumps was that they froze up. We always drained them after use, so they were never damaged when the water froze. However, the smallest amount of water in the pump will freeze the gears tight. Circulating a little antifreeze through the pump after it was drained helped alleviate the problem. The best fix, however, was to solder a 300-W electric heater (the Ogden Mighty Watt) to the pump. At the beginning of a set-up this heater is switched on, and by the time the pump is needed it is nice and warm. Once the hot water is flowing, of course, the electric heater can be turned off.

Gear pumps also have the failing that they are hard to prime. If they are pumping on air they will generally refuse to lift water more than about a foot. For this reason, the long suction hose was usually filled with water before it was put into service. Moreover, it is important to keep a good supply of water in the heater's built-in tank. Since this tank is above the pump, gravity aids the flow. It is water from this tank that reprimes the pump whenever air has been sucked into the system.

6.4.4 Drill Operation - Problems to Avoid

It is evident from the above that there is nothing automated about the system. Both the fuel and the spark are turned on separately, and if the fire goes out there is nothing to stop the fuel from spraying into the firebox. Moreover, if the water stops flowing, it boils; there is nothing to turn off the heat automatically. Consequently, the hot-water drill needs a dedicated attendant, someone who is well versed in the idiosyncrasies of the heater and who can react quickly to all its problems. For emergency turn-off, he has two large red 'panic' buttons he can punch to extinguish the fire and turn off the pump. This approach is both more efficient and less frustrating than trying to fight automatic systems that work very poorly in the cold. Our policy for most equipment in the Arctic has been 'the simpler, the better'.

When the system is shut down at the end of a working day, it is very important to drain the heat exchanger, the pump and all the hoses. Our heat exchanger is built into a framework that is made to be tipped up on end. When this is done, the water drains out smoothly and completely. The hoses are drained by walking underneath them from end to end. If there is a high snowbank nearby, the hoses can be draped over it with their centres at the top of the rise. Before draining all the water, it is very worthwhile to save four or five gallons of water in a jerry can. This will expedite the next day's start-up. The water must be put in a warm tent, of course.

FIGURE 57. Using the furnace burner to warm up brass 'quick-connects' At cold temperatures a quick-connect will not work because its O-ring is extremely stiff

On very cold days water that is lying stagnant in the pipes and hoses will freeze remarkably quickly. The usual scenario is that something relatively minor goes wrong, but the repair is not as rapid as anticipated, and half an hour flashes by. By this time the water in the brass fittings and the pump is probably frozen, and the job of thawing them out will add 20 or 30 minutes to the repair time. Metal objects can be thawed by holding them in the exhaust of an engine or in the flame of the furnace burner (Figure 57). However, if people are really careless and the water in the long hoses is allowed to freeze, the problem is appreciably worse. The stiff frozen hose has to be bundled up and fought into a warm tent where it may take an hour or more to thaw out and drain. One experience of doing this will usually make an operator ultra-sensitive to the problem of freezing hoses. If a problem isn't fixed in ten minutes, or so, it is usually good practice to take the time to drain the long hoses and everything else that could freeze quickly.

6.4.5 Making Holes with Hot Water

Once the hot water is available, it can be used for melting holes through the ice. In general this is quite easy, although there are a few tricks to learn. The simplest way of making a small hole though the ice is to run the hot water into a hole in the ice and pick up the cooled water for recirculation. A five-ft length of 1-in iron pipe is usually attached to the end of the outlet hose in order to give the operator some control in directing the water. Later, as the hole becomes deeper, the pipe acts as a weight to keep the hose (and, thus, the hole) plumb. The heat exchange between the jet of hot water and the ice at the bottom of the hole is very good, especially if the pipe is touching the bottom. This rapid transfer of heat means that most of the melting occurs at the bottom of the hole, and the diameter of the hole is not much bigger than the pipe, itself. However, the heat exchange at the bottom of the pipe is not perfect, and if a deep hole is allowed to stay full of water it will steadily increase in diameter so that, by the time the pipe drops into the ocean, the top of the hole might be 5 or 6 in in diameter. This increase in diameter is generally not desired, and it represents wasted heat and a slowed drilling rate. It is prevented in part by keeping the pick-up hose fairly close to the supply hose. (If it is too close, however, the pickup water will boil the next time it passes through the heat exchanger.)

In passing, note that the heat exchange between the hot water and the ice is good only if the hot water plays directly on the ice. If the hot water is kept within a metal heat-exchanger (a copper coil, for example), the transfer of heat is much slower.

Usually we need an ice hole large enough to allow some object (*e.g.*, a hydrophone) to be lowered into the water. This means that the hole must be larger than some minimum diameter over its whole length. To ensure that it is large enough, we attach a sizing device to the pipe 2 or 3 ft from the pipe's end. Our attachment has the shape of a flying saucer with a vertical hole drilled through it for the pipe. The return water is sucked into the hollow centre of the saucer through a series of holes drilled around its periphery, and from there the water passes up the return hose. The saucer ensures a minimum hole size since it will not allow the pipe to drop until the hole is big enough. However, once the hot-water pipe breaks through into the ocean, it no longer melts any ice since the hot water shoots directly into the ocean. To finish the hole once this happens, we interchange the two hoses at the water heater in order to reverse the water flow. Once this is done the hot water is blown out through the holes in the saucer, and the return water is drawn back up the centre pipe. This last portion of the drilling is somewhat slower than normal since the return water is cold ocean water, but it does get the job done.

We usually melt a large hole by making several passes of the hot-water drill, each time with a slightly bigger sizer. Let us suppose we need a 12-in hole. If we should use a 12-in sizer right from the beginning, much of hole will end up being about 24 in in diameter - far larger than necessary. This represents a serious waste of both fuel and time. It is much more efficient to drill a small hole and then ream it with consecutively larger sizers: first with the 6-in sizer and then with the 9-in sizer and then with the 12-in sizer. Once the 6-in sizer is through, much of the hole - perhaps half - is large enough for the 9-in sizer, which makes it possible to start the 9-in sizer half way down.

So far, we have talked only about making fairly small holes with the hot-water drill - holes in which all the ice in the hole was melted. Making a large hole (say 3 ft in diameter) in this way would take much too long. Larger holes are made by melting a vertical slot around a large piece of ice and then removing the ice core by one means or another. Our standard circular slot melters, or cookie-cutters as they are called, are 24 inches and 36 inches in diameter. They are made of two circular rings of copper tubing, the lower one drilled with holes pointing downward (to blast the hot water at the ice below) and the upper one with holes pointing upward (to recover the slightly cooled water). The two rings are separated a few inches by a web of metal. The pair of rings is controlled from the surface by four vertical rods and by the two water hoses

FIGURE 58. Jon Thorleifson looks on as Colin Ganton shows the workings of a 'bed-frame' cutter as he drills a large hole for the Autonomous Underwater Vehicle, Theseus.

Rectangular holes are made by cutting straight-line slots in the ice. We have made linear cutters that are three, four, five and seven ft in length, but there is no reason, other than that of strength, that they could not be made even longer. As often seemed to be the case, we started with a fairly complicated design and worked our way toward simplicity. The original cutters used two horizontal copper pipes. As in the case of the circular cookie cutters, the hot water was jetted out through a number of small holes drilled in the bottom of the lower pipe and the cooler water was picked up by holes in the upper pipe. (See Figure 58.) The two were separated and held in place by vertical pipes at both ends. One vertical pipe was plumbed to deliver the hot water, and the other vertical pipe was connected so that it recovered the pick-up water from the upper pipe. Their appearance gave them the name of the 'Bed-Frame Cutters'. Weights were tied to the bottom ends of the vertical pipes in order to keep the cutter in good contact with the ice and to keep the cutter head pointing downward. Any tendency of the cutter to turn about the horizontal axis was countered by the torque exerted by the weights. It will be noticed that the weights precede the cutter down the hole. For this to be possible, pilot holes must be drilled in advance for the weights and the vertical pipes, and care must be taken to ensure that the pilot holes are plumb. If the pilot holes are not parallel, the vertical pipes will bind in the holes. The cutter is kept level in its descent by the care and attention of the operators. They ensure that the hoses, which are marked for length, descend at the same rate.

Although these cutters worked quite adequately, they were complicated to make, and the necessity of predrilling plumb pilot holes made them cumbersome and slow to use. Recently, we have gone to a much simpler slot cutter. It is in the shape of a 'T' with the vertical pipe delivering hot water to the centre of the horizontal pipe (Figures 59 and 60).

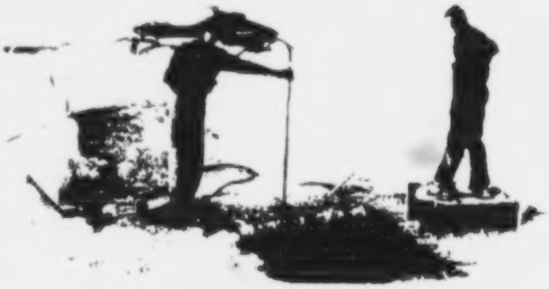

FIGURE 59. Darryl Gittins, who built the first T-cutter, and Jim Perkins are cutting ice blocks in relatively thin ice. Once the blocks were cut they were pushed down and under the ice sheet. Note the flooding. The weight of the surrounding snow was sufficient to depress the ice below sea level

Again, the hot water jets out through holes in the bottom of this horizontal pipe. In this simplified version, however, there are no vertical guide holes. The operator guides the vertical pipe and makes sure that the slot is cut accurately. This simplicity decreases the set-up time considerably. We were originally concerned that the slot would drift off vertical or, perhaps, would corkscrew as the cutter descended. However, we have been relieved to find that an operator can melt an accurate slice through ice that is at least 10 ft thick. A horizontal return pipe has not been incorporated into the design; the return water is simply picked up by a hose. Because the pick-up is farther away from the outlet, the return water is cooler than in the fancier models, and, consequently, the thermal efficiency

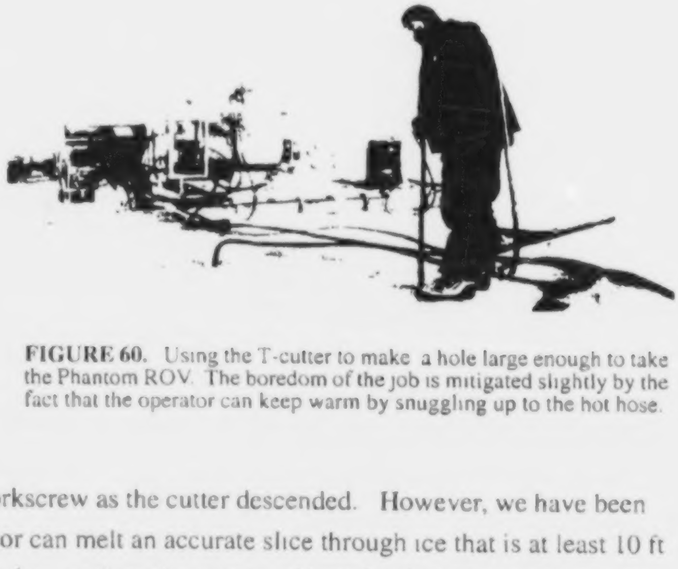

FIGURE 60. Using the T-cutter to make a hole large enough to take the Phantom ROV. The boredom of the job is mitigated slightly by the fact that the operator can keep warm by snuggling up to the hot hose.

is somewhat less. However, the advantages of simplicity and versatility more than make up for this disadvantage.

In the spring of 2000 we incorporated the next modification, which was to use ½" copper pipe rather than ¾" steel pipe for the cutter. The narrower pipe cut a narrower slot, and the drilling went faster. The ½" pipe, however, is weaker, and the T-shape had to be modified in order to provide better bracing. Figure 61 shows how the ends, rather than the centre of the pipe, were attached to the framework. Because of the angle end-bracing, this cutter, unlike the T-cutter, did not get trapped under the ice when it fell though. The cutter in this figure is 4-ft long. Another cutter 7-ft long was braced at both the ends and the centre.

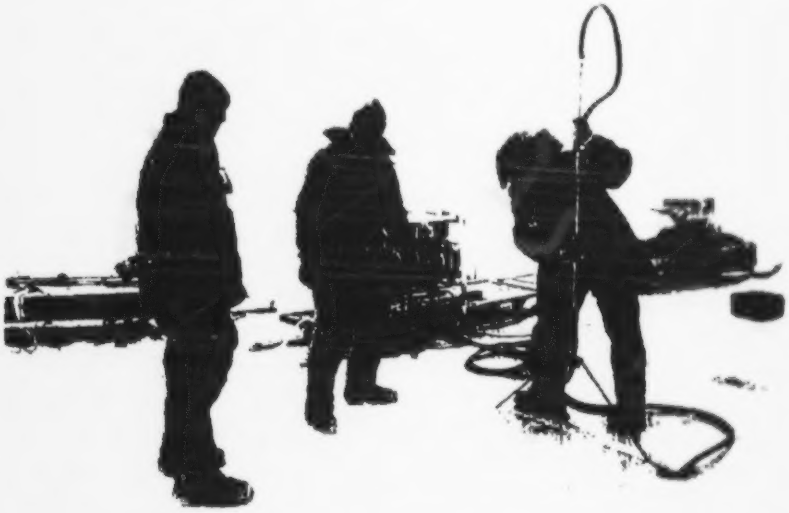

FIGURE 61. Garry Heard, Ron Verrall and Gerry White are cutting a linear slot with a cutter made out of 1/2-in. copper pipe and miscellaneous pipe fittings The cutting bar, itself, is below the level of the ice. It is fed water at both ends by the two angled braces. The vertical pipe was made of 3/4-in. pipe for extra strength By the time it gets to the ice level the slot has grown wide enough to accommodate it.

We have found that the most efficient way to cut out a series of ice blocks is to start all the cuts one after another and go down only a short distance (say two ft) with each one. All the cuts then progress roughly at the same rate, and the ocean is not breached until the drilling is almost all done. Once the hole is exposed to the ocean, the drilling seems to slow up. We speculate, too, that if we had a second pump to remove much of the melt water, the drilling would go even faster.

Once the ocean is breached, the blocks are cut out and removed one at a time. To free up more than one block would clutter the hole. Just before an ice block has broken free, the hot-water cutter is removed. Otherwise, the large block of free-floating ice might damage the cutter or, perhaps, trap it below the ice. Once the cutter is safely out of its slot, a pry bar (*e.g.*, a wooden 2x4) is used to break the ice block away from the sliver of ice holding it at the bottom. In fact, a judicious use of the pry bar can tell the operator when to remove the cutter; a tentative pull will indicate whether or not the block is ready to break off.

6.4.6 Removing the Ice Blocks

A great number of methods have been used for removing the blocks of ice from the hole. Pushing the blocks down and out of the way is the simplest method when it is possible. For it to work, however, the blocks must be small enough that two or three people can push them down with poles. This means that the blocks cannot weigh more than 1000 to 1500 lb, and smaller blocks require more cuts and, therefore, more cutting time. Moreover, the ice cannot be thicker than 6 or 7 ft. Otherwise the long, thin blocks of ice will cock in the hole and stick there. Finally, it must be realized that the underside of the ice will be littered with ice blocks if this technique is used. For many purposes this does not matter, but the possibility of their interfering with ropes, cables or hoses must be considered every time the method is used.

We now come to techniques for attaching lines to the ice blocks and lifting them out of the hole. Lassoing the block is quick and easy and is particularly useful when the block can be removed in one continuous pull. When we were making a 5 x 40-ft hole for the AUV Theseus in 1995 and in 1996, we lassoed 7000-lb blocks of six-ft-thick ice with a steel cable and lifted them out with the hoist of a travelling gantry (Figure 62).

A relatively small cylinder of ice, 20 inches in diameter and 7 ft long, say, and weighing 850 lbs., can be pulled out by the Posi-Track's fork lift in one continuous pull. The block is lassoed by a length of strong nylon rope, the rope is wrapped several times around a fork, and the ice is hoisted out (Figure 63). Although this method is wonderfully quick and easy, it has limited applicability since the Posi-Track is not always nearby.

A more common technique has been to use a heavy-duty tripod as a skyhook and a block and tackle or a powered winch to lift the ice. However, the lifting tackle is usually too weak to lift the whole block out in a single lift. In practice, therefore, the winch lifts as much as it can, and then the ice is cut off. The ice is repeatedly lifted and cut until it has all been removed. This technique has the annoying disadvantage that every time a length of ice has been cut off, the remaining ice falls back into the hole and must be lassoed again.

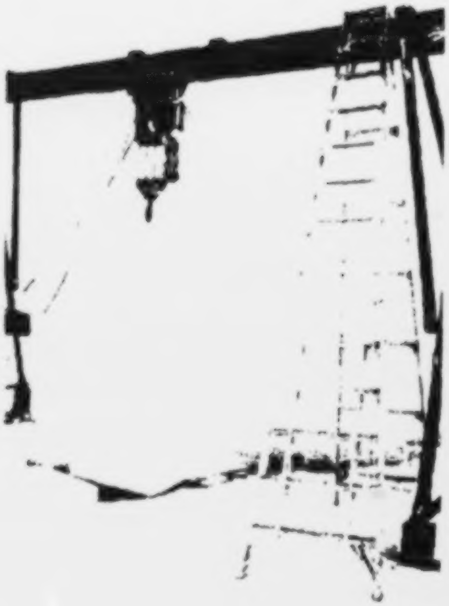

FIGURE 62. A travelling gantry being used to remove large blocks of ice. Here we were developing techniques for making a very large hole for a 20,000-lb autonomous vehicle.

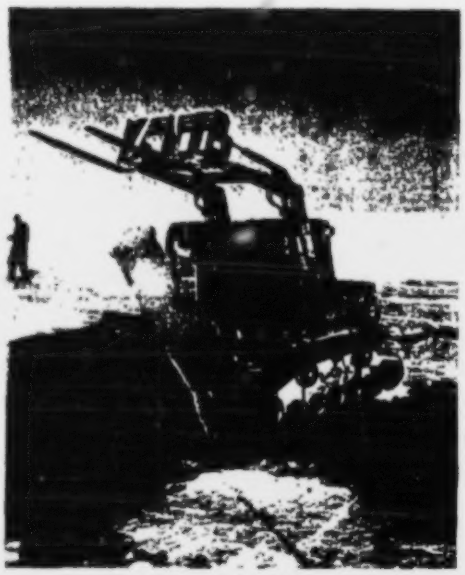

FIGURE 63. A Posi-track lifting a cylinder of ice that has been cut by a 24-inch 'cookie cutter'

When the block cannot be pulled out in one piece, a better way to grip it is to melt a small hole down through its centre and then hook the block with a line and toggle. The block is hoisted as high as possible with this line, and then pie-shaped pieces of ice are sliced off with a chainsaw and ice chisel (Figure 64). We take care, of course, not to cut into the supporting rope or chain. The advantage of lifting the ice by means of a toggle through a central hole is that the ice block does not fall back into the hole every time a piece of it is cut off.

Recently, we have devised a way of lifting the ice blocks using the substantial power of a large skidoo. In previous years we had tried to use a skidoo to jerk the blocks out of the hole, but we had found it difficult to get the blocks up and over the lip of the ice hole without sending the driver up and over the handlebars. Consequently, the blocks had to be cut quite small for this to work.

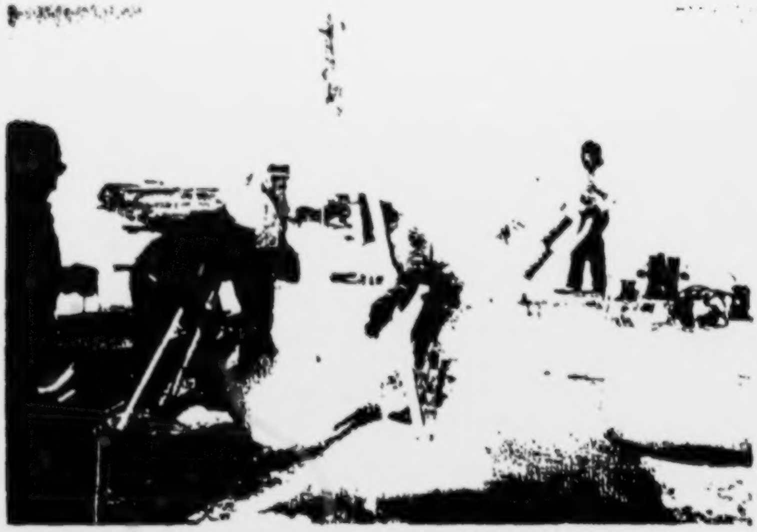

FIGURE 64. Lifting the ice core with a tripod and electric winch. The ice is lifted by a toggle dropped through a central hole. When the winch has lifted as much as it can, the ice is cut off and pulled away by sled. Note the two 36-inch holes already drilled with a circular 'cookie cutter'. In the background, the hot-water drill is being tipped up on end to drain its heat exchanger.

The modification that made extraction efficient was the A-frame ice-lifter (shown in Figures 65 and 66).

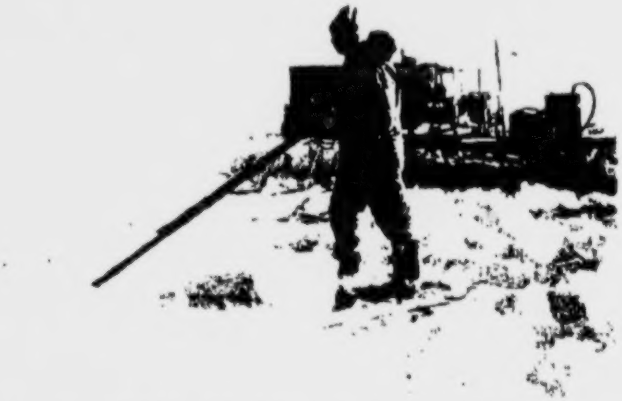

FIGURE 65. Garry Heard is holding the A-frame until the snowmobile (off the picture to the left) takes the pull. Here, the plug has just started to rise.

A triangle about six ft high and four ft at the base was built out of 2 x 2 square structural steel tube. Sharpened metal plates were welded to the bottom of the legs. They grab the ice and help ensure that the A-frame does not slide at the beginning of the pull. A rope is attached to the ice block, either by lassoing it or by hot-water drilling a small hole at an angle through a corner of the block.

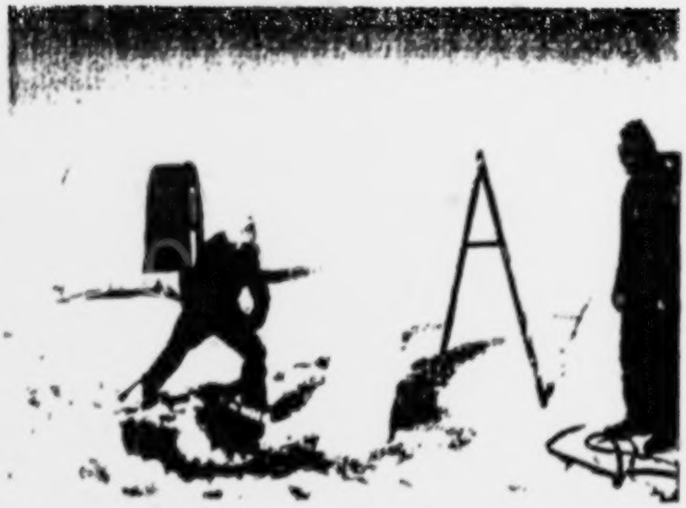

FIGURE 66. Here the ice plug has become stuck in the hole, and Bobby Fisher is wielding a heavy axe. At other times, chain saws have been used to cut the ice block

The rope is then wrapped around the upper end of the A-frame, the A-frame being bent over toward the ice block at a fairly shallow angle to the horizontal (say 25 or 30 degrees). The A-frame is held in place (by hand) while the rope is taken to the waiting skidoo. As the skidoo takes up the tension, the A-frame rotates upward, bringing the ice block up with it. In this way a large block can be lifted out of the hole and slid onto the adjacent ice. In fact, the blocks that we have lifted onto the surface were sometimes too big to be dragged away whole; they had to be cut in half. If the block is too heavy to be lifted out or if it jams in the hole, the skidoo holds it in place while it is cut off with a chainsaw or an axe (Figure 66). Once the ice block is up on the ice and haulable, the skidoo pulls it away to a respectable distance. The A-frame, which is attached by only a couple of turns of rope, usually falls off as the block is dragged away.

6.5 Choosing Where to Drill - Finding Thin Ice.

The job of drilling or cutting a hole through the ice can be made much easier by the simple expedient of finding thin ice. In some areas there is not much choice; the ice is all uniformly thick. However, in areas of rough ice, such as that shown in Figures 65 and 66, the ice thickness can easily vary from 1 m to 10 m. The thick ice will be old, polar ice, or perhaps it will be a relatively fresh rubble field. The thin ice usually consists of very small patches that were open water several months previously. The problem is to recognize the thin bits, and this is sometimes quite hard, especially if the whole area is covered with wind-blown snow drifts. One's ability improves with experience.

There are several identifying clues that are worth looking for. First of all, when an ice ridge is formed, a small lead will often open up after the pressure event is over. This will be found immediately adjacent to the ridge. Similarly, there are sometimes large pieces of old polar ice in the midst of newer, but still thick, ice. The two different types of ice will be driven at different velocities by the wind and current, and this will generate small areas of open water around the large chunks.

Once you recognize the general area in which to look, you then search for ice that is slightly depressed relative to the surrounding ice. The depression will often indicate a smaller freeboard, and this is often due to the ice being thinner. However, thin pieces of ice are usually hard to spot in areas of heavy snow cover.

A smooth surface is also a good clue, especially if the snow has blown off and you can see the ice. Thin ice that is only a few months old is smoother, warmer and saltier than old ice. Old ice is rough because of slush that has frozen into its surface. Often a fair bit of snow has to be shovelled off the ice in order to have a look at it, and the sound and feel of the shovel scraping the ice will sometimes tell you immediately whether the ice is old and thick or whether it has possibilities. If the ice looks like it might be thin, start a 4-in. hole with a Finbore drill. After the drill has gone down a few inches, taste the ice chips. If the ice is only a few months old, the chips will taste salty. Moreover, the drill will cut through warm and salty new ice much more quickly than it will cut through cold and fresh old ice. If the signs continue to look promising, finish drilling the hole. That is the only way to get a truly accurate measure of the thickness. And, if you have read the ice well, the amount of drilling will be minimal. Once the four-inch drill is through to the ocean, finish the job by attaching a string to a weight and dropping it down the hole. This will reassure you that the ice is not rafted.

7.0 Installing and Recovering Equipment

7.1 Basic Techniques

Making the ice hole (Section 6) is the biggest step toward getting equipment into the water. Once that is done, the rest of the installation is usually quite straightforward. Basically, one just lowers the equipment and ties it off. There are, however, some problems that might trap the inexperienced, and there are a few tricks that can make recovery and depth-adjustments a little easier.

Before making the ice hole, one needs to look ahead to the removal of the equipment. First of all, does it really have to be removed, or can it just be left there? When will it have to be removed? How often (if at all) does the depth of the instrument have to be changed? The answer to these questions will determine the size of the hole and the equipment that has to be available to reopen it.

If the equipment (*e.g.*, a hydrophone or a vertical array of hydrophones) is to be left in place for several weeks, then there is no point in preventing the hole from freezing. One drills a hole just large enough for the equipment, lowers it to the correct depth, ties off the cable and lets it freeze in.

If, on the other hand, the equipment has to be raised and lowered a few times over the following week, one approach is to make a fairly large hole, say two feet in diameter, and support the cable so that it goes down the centre of the hole. After the installation, the hole is covered with styrofoam insulation and snow to minimize the rate at which the surface water freezes. When the equipment is to be moved, the insulation is removed from the hole, and the surface ice is chipped off. This is usually sufficient to free the cable. It is important to keep the cable away from the edge of the hole where the ice is forming. Otherwise, the cable will be incorporated into the new ice at the hole's edge.

The hole can be kept open longer by carefully shaving the sides of the ice hole with an ice chisel. The top metre, or so, of ice is the most important because that is where the ice is coldest, and that is where the hole diameter will be contracting the fastest. Fortunately, this depth can be reached quite easily with an ice chisel. The shaved ice is, of course, shovelled off the surface of the hole.

Another approach that we use more and more is to use the hot-water drill to free up the cable whenever we want to move it. The hot-water drill has, in fact, made this job quite easy. If the cable is to be moved only once or twice we do nothing special to prepare the hole. However, if the cable must be melted out several times we sometimes line the hole with PVC plastic pipe. The pipe contains the hot water so that only the ice that we want melted does, in fact, get melted. This dramatically shortens the drilling time, and the technique is particulatly useful and effective when the cable is faired with hairy fairing, which normally attaches itself solidly to a large volume of ice.

7.2 Alcohol-Filled Pipes

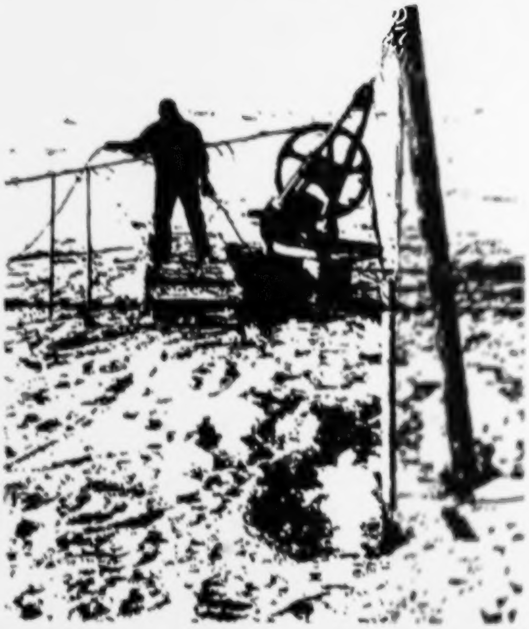

FIGURE 67. A cable going down a 2-in. pipe filled with alcohol The alcohol, which does not freeze, expels the water and allows the cable free movement up and down.

Sometimes the equipment has to be lifted or lowered quickly and often. We once had an array of about ten hydrophones - each down its own hole. We wanted to be able to move all of them together - *i.e.*, in as short a time period as we could manage. Moreover, we had placed the hydrophones in a large old pan of ice where the thickness varied from about 6 m to 10 m. To speed the process of adjusting the hydrophone depths we put the cable down a 2-in plastic pipe that was slightly longer than the ice was thick (see Figure 67). This pipe was then filled with ethanol (ethyl alcohol) to keep the cable free. Note that ethanol does not seriously pollute the environment. Alcohol is water soluble and is a naturally occurring product of fermentation. In previous decades, diesel fuel had been used for similar purposes, but it was harder on the environment (and much messier for the workers).

The density of ethanol is only about 0.8, as compared to 0.9 for ice and 1.0 for water. This means that when the plastic pipe is full of alcohol right down to the bottom of the ice, the top of the alcohol column is appreciably above the ice. For example, ice that is 5 m thick has a freeboard, (the height of the ice above the water in the hole) of about 0.5 m, and the height of the ethanol in the pipe is about 0.5 m above the surface of the ice. To ensure that the pipe was filled we added alcohol until the level stopped rising in the pipe.

When the experiment was over, we recovered all the ethanol we could, and then we used the hot-water drill to melt out the hydrophone, cable and pipe.

7.3 Keeping a Large Hole Open

Occasionally it is necessary to keep a larger hole open and clear for a substantial length of time. The usual way to do this is to erect a tent or small building right over the hole. With a stove so handy, there are several ways that the hole can be kept free of ice. The simplest method is to keep a pot of water on the stove. When the water gets hot it is poured into the ice hole, and a new pot of cold water is scooped up and placed on the stove. A second method, which takes a little longer to set up but which works better in the long run, is to pump the water from the hole up through a small radiator and then back down into the hole. The radiator, which is placed flat on the stove, transfers a substantial amount of heat to the water. The pump can be a small battery-operated aquarium pump. Either technique will keep the surface clear of ice particles, but the pump can inject the warmed water well down the hole to keep it from necking-in.

7.4 Protecting the Cable at the Bottom of the Ice Hole

Some cables, such as small fiber-optic cables, require particular protection at the bottom of the ice hole. In one instance our fiber-optic cable approached the hole almost horizontally (from a distant site), and it was forced to make a sharp turn as it entered the bottom of the ice hole. We were concerned that a small-radius turn might damage the cable, and we were also worried that if a cable splice should be pulled up to the hole it (the splice) would be caught in the soft ice at the bottom of the hole. To obviate such problems we lined the holes with pipe (18-in plastic sewer pipe) and attached a flared fiber-glass 'bell' at the bottom of the pipe. This worked very well, and its only disadvantage was that it required a 36-in ice-hole for its installation.

7.5 Raising Equipment

There are many ways to lower and raise equipment. The most controlled way to handle heavy equipment is to set up a quadrapod - complete with electric winch - on the ice over the hole. This, however, is time-consuming. If the package is not too heavy, the simplest way to handle it is to lower it by hand and to raise it by 'walking' it up - letting the leg muscles do the work.

A skidoo can pull up a much heavier weight than can be pulled up by a human, and it can pull up any load much faster. However, the use of a skidoo demands good communication between the person driving the skidoo and the person standing beside the hole. Also, some sort of marker needs to be placed on the cable well above the instrument package so that the person watching the hole knows that something delicate is approaching. This marker must be attached very tightly to the cable so that it will not slide as the cable comes up through the ice hole. (We know this from painful experience.)

It is also very useful to put some sort of sheave at the surface so that the cable is not forced to turn through a small radius as it goes over the edge of the ice. We have used something as simple as a small aluminum toboggan turned upside down by the hole (Figure 68). The sheave in Figure 67 shows another technique. The pulley is a plastic bicycle wheel, which has excellent bearings and is quite inexpensive.

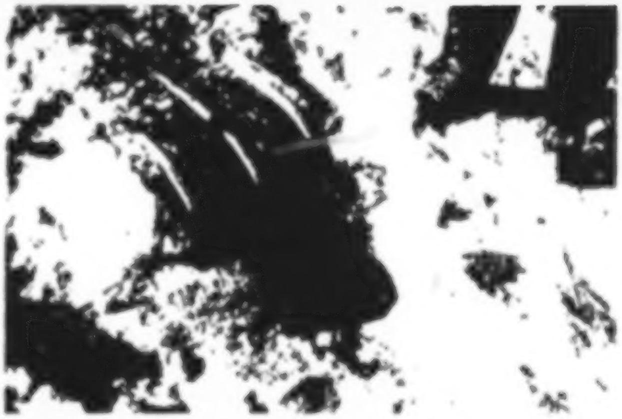

FIGURE 68. Small sled being used to guide a cable over the edge of the ice hole.

A 4 x 4 wooden post frozen into an ice hole can be a useful tool to help lower and raise equipment. The post can anchor a battery-operated boat capstan, for example, as the capstan hauls up the equipment. A small amount of water poured down beside the 4 x 4 will soon freeze it in and prevent it from rotating. It should be noted that an unmodified 4 x 4 will not go down a 4-inch hole; it needs to have its corners planed off.

7.6 Techniques for Releasing Weights

7.6.1 Dissolving Life-Savers

Sometimes one would like to have extra weight on the package while it is being lowered, and then have the weights fall off. For example, we occasionally lower a hydrophone that is attached to the main cable by a 10- or 15- m length of neutrally buoyant cable. (This neutrally buoyant cable is to decouple the hydrophone from the vibrations of the main vertical cable, which is held down by a substantial weight.) If the package were lowered without any preparation, the neutrally buoyant cable would float upward and entwine itself around the main cable. In order to keep the cables from tangling we attach a small weight (*e.g.*, one lb) to the hydrophone so that the hydrophone and its cable will lead the main weight down through the water column. However, we attach the weight so that it will fall off after a suitable period of time. We do this by tying the weight to the cable with a string that passes through a candy 'Life Saver'. The attachment is rigged so that the weight and the string fall away when the Life Saver dissolves. The hard types (*e.g.*, Five-Flavours) are preferred because they are strong. Moreover, since they are non-porous they take a good 40 minutes to dissolve in the cold sea water.

7.6.2 Burn-Wire Technique

Another way of releasing weights from an instrument package is by the so-called 'burn-wire' technique. This is particularly useful when the weights need to be attached for a length of time that can not be predicted beforehand. Perhaps, for example, the weights are not to be dropped until the ice stops moving, and this time can vary from zero to several weeks. The catchy name 'burn-wire', however, is somewhat misleading. The wire does not 'burn'; rather, it is eaten away by electrolysis. The procedure is to attach the weight to the instrument package by a fine steel wire and to connect this wire to an electric cable that goes to the surface. When the time comes to release the weights, the electric wire is attached to the positive post of a car battery, and the negative post is coupled to the sea water by means of a short piece of heavy wire - electrical braid, for example. (An ammeter will indicate that the electrolysis is happening.) After several minutes the steel wire is eaten away by the electrolysis, and the weight falls off. It is important to note that only a small length (*e.g.*, 2 mm) of the steel wire should be exposed to the sea water. The rest of it should be insulated. This concentrates the electrolytic action on a small area and speeds the desired result. The wire should be as small as possible - consistent with the required strength. The smaller the wire, the faster it will be eaten away. Moreover, copper wire should not be used as a substitute for the steel. When electrolysed, a copper wire gets coated with a gelatinous insulating compound, and the electric current drops significantly. Even if the electrolysis worked, copper would be a poor choice since it is so much weaker than steel.

7.6.3 Corrodible Bolts

A magnesium bolt that makes electrical contact with a steel plate will act as the anode of a salt-water battery, and it will quite quickly corrode in sea water. These corrodible bolts can be used to hold equipment together for a short period of time (several hours to several days, depending on the design). We once installed an array of hydrophones on a rough, rocky bottom. We wanted to ensure that the cable was not suspended above the bottom where it might strum in the current and make noise. On the other hand, we wanted to install the array under an appreciable tension so that it would be straight. We accomplished both requirements by connecting each pair of hydrophones with a steel cable that was somewhat shorter than the electrical cable that joined them. The array was laid under tension, and a few days later the magnesium bolts that were fastening the steel cable to the hydrophones corroded away and allowed the hydrophones and the electrical cable to settle to the bottom.

7.6.4 Mechanical Bottom-Releases

At other times we have wanted to lower the Phantom ROV quickly to the ocean bottom - perhaps 600 m down. To help Phantom drive itself downwards we sometimes added 10 or 20 lbs of scrap-metal to the vehicle and arranged that it fall off when Phantom reached the bottom. Figure 69 shows the quick release that we used to drop the weights away. It is just a piece of bent quarter-inch rod. The hook passes either through a rope loop (as shown) or over a metal strut in the ROV framework. When the weight hits the bottom the hook rotates and falls away. The mechanism is simple, reliable and cheap, especially when old pieces of iron are used for the weights.

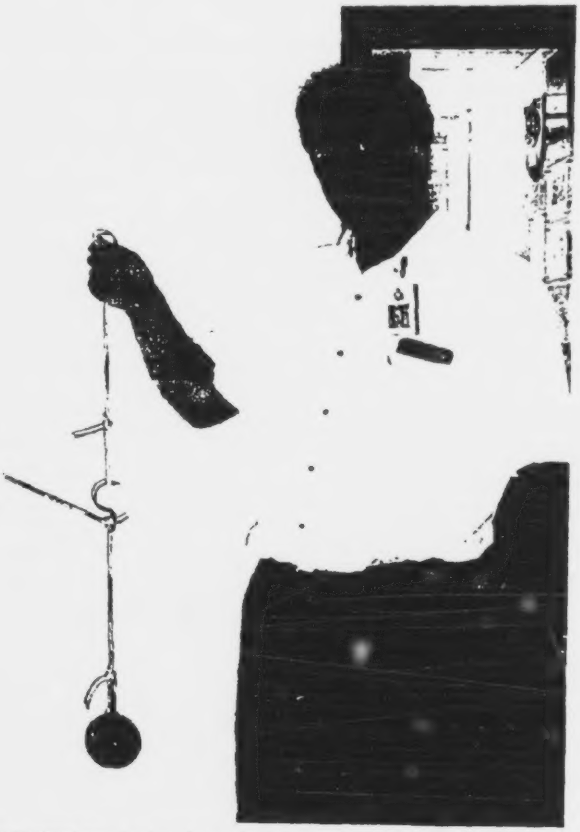

FIGURE 69. A simple and inexpensive release that we use for dropping a weight off at the bottom of the ocean.

7.7 Recovering Equipment that has been Installed for the Long Term

Occasionally, we place equipment on the ocean bottom to record information (ambient noise, for example) for a long period of time. Typically, the recording package would be deployed during one spring field trip and recovered the next.

The usual approach is to build a recording package that floats but then attach heavy weights to sink it. In order for the recording package to be retrievable, it is attached to the weights by means of a link that can be commanded acoustically to release. Once released, the recording package will float up to the surface where it can be recovered.

In practice, the equipment is lowered by a line that can be slipped or released. Once the equipment is in place on the bottom, a careful GPS reading is made. The following year the site is revisited by Twin Otter or helicopter. Sometimes the ice in the immediate neighbourhood is too rough for a camp, and the recovery team must wait and hope that the ice will move. Once a reasonable piece of ice is over the site, they drill through the ice, lower a transponder and 'talk' to the acoustic release to make sure that it is still functioning. With this acoustic link they can also measure their distance to the release, and this gives them reassurance that they are not too far away from the 'on top' position. Once they are ready, they command the release to open its link. If all goes well, they can monitor the decreasing range as the recording package, the acoustic release and any associated floats rise to the surface.

Because the releases are less than totally reliable, their operation is the most problematic step in the whole procedure. Usually, in fact, the recording package is held by two releases in series in hopes that at least one of them will work.

Once the packages have floated to the surface, they must be found and retrieved through the pack ice. Ranges measured from several holes to the acoustic release will give a fairly good estimate of its position. Another technique for finding the package involves Pieps beacons, the radio beacons that are used to locate people who have been buried by an avalanche. The float that holds the Pieps beacon transmitter is rigged to turn on it side when it rises against the ice. This change in its attitude closes a switch (*e.g.*, a mercury switch) and connects the beacon to its battery. The operators then walk the ice surface looking for the beacon just as they would look for a skier buried beneath the snow.

Once they feel they are on top of the beacon, the recovery team cuts a hole in the ice. One way of finding the equipment and putting a line on it is to use a remotely operated vehicle (ROV), such as the Phantom (discussed in Section 7.9). Another way of recovering the equipment is to send down divers. We have not done this, but our American colleagues do this as a matter of course. Once the divers (or the ROV) find the equipment and put a line on it, the recovery is essentially done.

7.8 Installing Cables Across the Foreshore

There are many situations in which it is very desirable to run a cable from a sensor package on the ocean bottom to a site on the shore. Such an installation allows one to look at the data in real time; it enables the collection of much more information than does an underwater recording package, and it allows power to be sent down the cable, thus greatly extending the lifetime of the system. There are problems with this scheme, however. The obvious draw-backs are the high cost of the cable and the difficulty of laying it on the bottom, especially if the ocean is covered with ice. One of the biggest difficulties, however, is that of getting the cable safely across the foreshore, and this problem is particularly insidious since the job seems relatively easy – and it isn't.

The problem is due to sea ice being pushed up onto the shore. The heavy ice, with enormous pressure behind it, bulldozes away gravel, rocks and boulders – both above and below the waterline. Once the ice scrapes down to the level of the cable (assuming that it has been buried), the cable's longevity will be measured in days or weeks. Even the most heavily armoured cable cannot withstand the action of sea ice freezing to it, dragging it and abrading it.

Our early experience involved making trenches with high pressure water or with explosives. We would bury the cable at the bottom of the trench and cover it with rocks and gravel. In every case but one the cable did not last a whole year. Eventually we came to the realization that this was a serious problem that could not be treated as a minor add-on to the main job of installing the underwater equipment. Its solution would involve substantial expenditure, both in time and money.

Our solution was to drill a hole through the overburden and the rock from a point high on the shore out to a spot on the ocean bottom that was deep enough to escape the scour of deep ice keels. The holes were drilled by commercial hard-rock drillers . In one instance we drilled a relatively short (about 60 m) straight hole that intersected the ocean bottom (Figure 70). The water depth at the exit point was 7 m, which was deep enough since the ice in the region was seldom older than first-year ice, and it was relatively thin. At Alert, the only other location where we drilled through the fore-shore, the hole was made to curve upward so that the hole entered the ocean bottom at a fairly steep angle. The contractor's report[19] describes the operation, and a Scientific American article[20] gives a good description of the art of drilling a curved hole. The length of the hole was 281 m, and the water depth at the exit location was 36 m. The exit was so deep because we were worried about the scouring action of the deep keels of the Arctic pack ice. In fact, the planned depth had been 50 m, but a series of problems kept us from pushing the hole as far as had been planned. So far, the cable seems to be surviving nicely. It was installed in the spring of 1994, and we know it was in good shape in the spring of 1999.

In both installations the hole was lined with steel pipe (the drill stem), and a cable was pulled through the pipe with a tag line. The tag line had been blown (with water) from the top of the pipe to the bottom, where it was grabbed by an ROV. The tag line was attached to the cable, which was stored on a reel sitting on the ice, and the tag line and cable were pulled to the top of the pipe. At that point the cable was spliced at both ends.

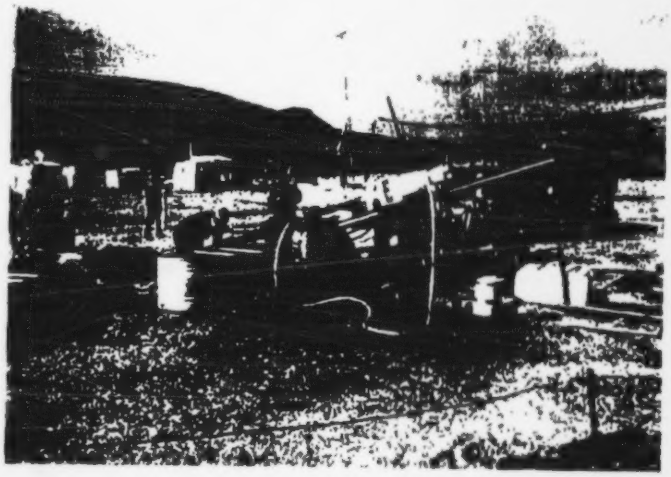

FIGURE 70. Drilling a straight slant hole on Devon Island. This intersected the ocean at a depth of 7 m

We feel that these cross-shore pipes, which were installed at appreciable expense, could be reused in the future simply by pulling out the old cable and installing a new one. The only difficulty might be with ice frozen in the pipe below the water level, but we think that it wouldn't take much ingenuity to melt this ice plug with our hot-water drill.

7.9 Remotely Operated Vehicles (ROV's)

Remotely operated underwater vehicles have become very important to us in our installation and recovery of equipment. We have used them to string lines under the ice, to inspect equipment both on the bottom and hanging from the ice, to help recover recording equipment left on the bottom, to find and help repair broken fiber-optic cables and to act as a tender to the 10-tonne autonomous vehicle, Theseus. We have had experience with two vehicles: the Seamor, which is quite small, and the Phantom, which is larger, heavier and much more powerful. Although we have had good success with both vehicles, this discussion is not to suggest that we have made an exhaustive ROV study and found these two units superior.

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The Seamor, which is built by Inuktun Services Ltd. of Nanaimo, B.C., Canada weighs 8 kg (18 lbs) in air and has a depth capability of 45 m (150 ft). The length of its umbilical is also about 45 m. In a pinch it will go through a 2-ft-diameter hole, but generally we cut a 3-ft hole for it. Its chief tool is a colour video camera, and it is mainly used for inspections. Its advantages stem from its light weight, its ease of shipping and handling and its minimal hole requirements. Its disadvantages are due to its short umbilical, its low thrust and its lack of manipulators.

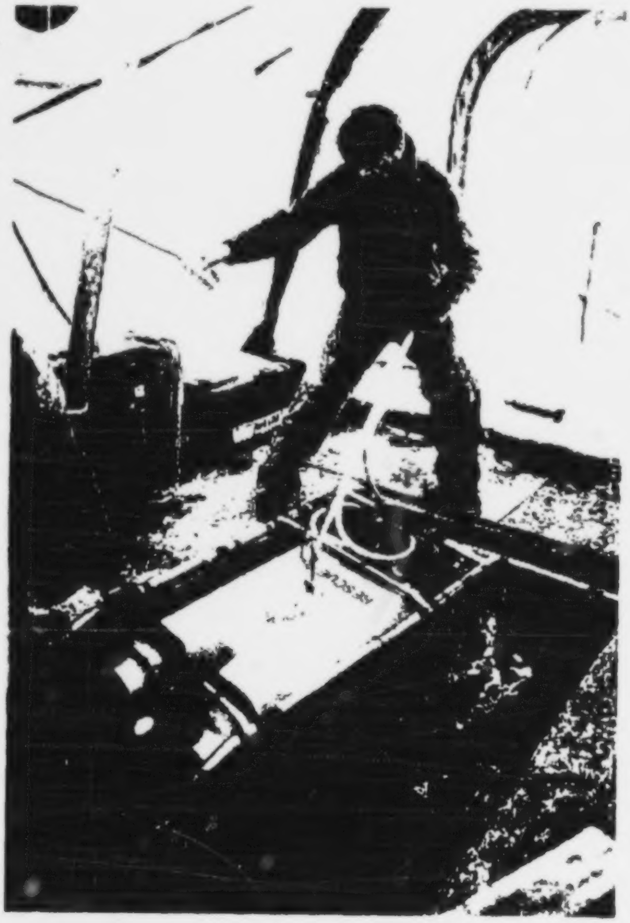

FIGURE 71. Jim Milne using the monopod and a winch to haul the Phantom ROV out of an ice hole

The Phantom, built by Deep Ocean Engineering of San Leandro, California, is a much more capable vehicle. It has an umbilical cable 670 m (2200 ft) long, and it can go to a depth of 610 m (2000 ft). Moreover, it has a thrust powerful enough that it can pull all this cable. We, ourselves, have used it extensively at the end of its tether at depths of about 500 m. It has the capability of carrying and operating various manipulators - cutters, claws, etc. And, of course, it has a colour video camera.

This capability does, however, come at a cost. The Phantom is substantially heavier and larger than Seamor (Figure 71). It weighs about 96 kg (210 lbs) in air, and it requires a hole in the ice of about 1.2 x 2.1 m (4 x 7 ft). Also, it requires a 220-V 6-kW power supply, which is not light. The spool holding 670 m of 2-cm-diameter umbilical cable is heavy and cumbersome to take out to an ice camp in a small aircraft. However, lest this sound like ungrateful whining, I hasten to state that we are quite willing to put up with the extra effort in order to have the underwater capability Phantom provides.

One of the difficulties of working with Phantom is the heavy job of pulling it back up to the surface. Although Phantom has plenty of thrust to bring itself up, the operators must be careful not to over-run the umbilical cable and tangle it. In practice the Phantom supplies only part of the necessary lift, and the umbilical supplies the rest. Thus the people pulling the umbilical have to overcome the drag of the Phantom as well as the drag of hundreds of metres of cable moving though the water. To bring this all up at a slow walking pace usually requires five or six people pulling quite hard, and a 550-m pull is a long tiring task. On a typical Phantom-operation day this would have to be done three or four times. After a season or two of this we looked for something that could help us with this grunt work. It came in the form of a capstan called the 'Mule'. It consists of two car wheels, complete with tires, mounted side by side on a single axle. The tires are touching one another, but the angle between them is steep enough that the umbilical is grabbed by the V-shaped junction. An electric motor drives the axle; the axle turns the wheels, and the wheels pull the umbilical at a slow walking pace. The Mule, complete with frame, motor, etc., is placed at the edge of the ice hole; the umbilical is laid over the top of the tires, and the motor is turned on. As long as someone pulls the umbilical hard enough to maintain good contact between the tires and the umbilical cord, the Mule pulls up the cord and the Phantom. If the Muleteer stops pulling the umbilical, the tires slip, and the Mule, like any good capstan, stops pulling.

This arrangement was a great success. The Mule and one person working at a relaxed pace replaced five or six people working very hard.

8.0 Miscellaneous

8.1 Gasoline and Diesel Engines

When it comes to our dependence on the internal combustion engine, the Arctic is not much different than the south. In the Arctic we use gasoline engines in skidoos and electric generators, and we use diesel engines in trucks, fork-lifts and electric generators. We would be hard-pressed to do without them, and so we learn to cope with the difficulties of making them work in the cold.

There are three main reasons why an engine starts poorly in the cold: the fuel does not ignite well at cold temperatures; the engine oil stiffens up so that it acts more like molasses than a lubricant; and car batteries lose a lot of their capacity at very cold temperatures.

For a pull-start gasoline engine, such as a small skidoo or a small motor-generator, the last reason does not apply. The problem with these engines is that they don't get enough fuel mixed with the intake air to form an explosive mixture. The gasoline does not evaporate well at the cold temperatures, and the fuel mixture ends up being too lean to ignite. The old farmer's trick of removing the spark plug and pouring a little gasoline directly into the cylinder usually works well. The gasoline in the cylinder keeps the engine running for three or four seconds, which will usually heat the engine enough to keep it running. Another trick is to pour raw gasoline directly into the engine's air intake. Most of the new snowmobiles have a better and less time-consuming way of adding gasoline to the air supply. They have a thumb-operated pump that squirts gasoline directly into the air stream after the carburettor. This works so well that we added a similar pump to some of our gasoline-powered motor-generators.

A diesel engine has problems that are similar in that the fuel does not want to burn, but its reasons for not starting are somewhat different. Unlike a gasoline engine, a diesel engine does not draw in a mixture of fuel and air into its cylinder. Rather, it sucks pure air and then compresses it to a volume of only one fifteenth to one twenty fifth of its original volume. When this is done quickly and adiabatically, the air gets extremely hot - hot enough that the fuel will ignite as it is being sprayed into the cylinder. If, however, the engine is being cranked too slowly for the compression to be adiabatic, and if the surroundings are very cold, the air will not heat up enough to ignite the cold fuel. This starting problem can be overcome in several ways. Some diesels, especially the larger ones, incorporate an electrically heated glow-plug in the cylinder. This local hot spot assists with the ignition of the sprayed-in fuel. (The glow-plug is turned off once the engine starts.) In very cold weather, however, the glow-plug is sometimes not enough. Our Posi-Track uses a glow-plug, but after a cold night the engine still has to be heated externally with, for example, a Herman Nelson (Figure 72).

FIGURE 72. The Posi-track diesel engine being heated by Herman Nelson heater.

Smaller diesel engines, like our Yanmar motor-generator, do not have a glow-plug, and they will not start when they are cold. They have to be brought into a warm room (or tent) and be placed by the stove - preferably well up off the cold floor. After an hour or so of this warming, they will start. If they are only moderately cold, they will often start if they are cranked electrically but not if they are cranked by hand. The faster cranking speed of the electrical start means that less heat is lost from the air to the cylinder walls, with the result that the compressed air is hotter and more likely to ignite the fuel.

Another cold weather trick for starting diesels is to dribble a volatile fuel into the air intake while the engine is cranking. Ether (ethyl ether) used to be a popular candidate for this job, but WD-40 (the spray lubricant) seems to have taken over, probably since it can be found almost anywhere. The propellant in WD-40 is propane, which is the fuel that is being burned by the engine. The oil in the spray is useful in lubricating the cylinder walls. However, all of these fuels (ether, propane, etc.) are hard on the engine since they explode much more rapidly than does diesel fuel, which burns as it is being injected. Thus, the pressure in the cylinder may become high enough to damage the bearings or stretch the head bolts. These starting fluids should be used as sparingly as possible.

Cold batteries have only a fraction of the cranking energy of a warm battery. Just when you need an engine to turn over rapidly because of cold fuel problems, the battery reneges on its job. When trying to start our Posi-Track on a cold morning, we would often take out a warm battery and connect it in parallel across the Posi-Track's battery. Once the engine started, we would take the extra battery back into the warm and put it on charge.

Cold lubricating oil is another problem. It is exceedingly viscous, and this slows the motion of all the moving parts, particularly the piston sliding up and down in the cylinder. This makes it very difficult for the cold, weak battery to crank the engine. We generally use 0W30, which is about as light an oil as is commercially obtainable.

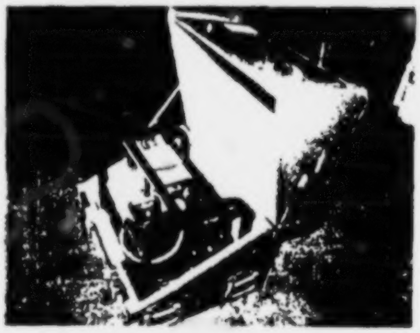

FIGURE 73. Carrying box for motor generator. The open lid protects the generator from the wind, and the warm pocket of air keeps the generator bearings warm and lubricated.

Motor generators have their own particular lubrication problem. The engine and the generator are attached together in a single housing, so the generator bearing that is close to the engine is kept warm, and the lubricating oil does its job. However, the bearing at the other end of the generator does not get any heat from the engine. As a result the lubricating grease or oil stays cold and does not protect the bearing properly. We realized this one year after we lost a bearing in the cold weather. We cured the problem by building a box that kept a bubble of warm air around the motor-generator (Figure 73). The box also made a very good shipping and carrying case; it protected the engine from other freight that was stacked on top.

8.2 Miscellaneous Heaters

The Herman Nelson heater has been mentioned several times in the preceding sections. It was a very popular heater in the Arctic for warming aircraft engines and other machinery. (See, for example, Figures 26, 30 and 72.) It had an internal heat exchanger so that its warm air was uncontaminated by the exhaust of the burner. The so-called 'prime mover' was a motor that drove the fan that moved the hot air produced by the burner. The prime mover was sometimes an electric motor, but it was usually a gasoline engine. This engine was mounted in an easily removed framework so that it could be taken into a warm building.

The Herman Nelsons are no longer made, but a similar heater is now made by Fiesta.

The big disadvantage of this type of heater is its size and weight - problems that stem from the need for an internal heat exchanger. We often use other, lighter heaters (Homelite, for example) whose hot air is mixed with the burner exhaust. Although these heaters cannot be used to heat living or working areas, they are just fine for warming engines and other equipment. Their impeller fan is usually electrically operated, so they do need 110-V electric power.

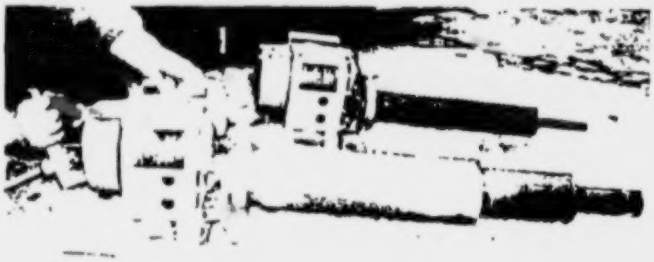

FIGURE 74. The Swingfire that is being started was designed to produce lots of reasonably hot air. The one in the background has an exhaust tube (surrounded by a screen) that is designed to get red hot and radiate heat to the innards of a tank engine. Its exhaust is not designed to entrain extra air, and so the exhaust temperature is extremely high.

Another type of heater that we use at ice camps is the Swingfire (Figure 74). They operate on the principle of a pulse-jet engine, and, to those that remember, they sound just like the V-1 buzz bombs flying over England during World War II. Apparently, the Swingfires were developed by the Germans to help start their tanks and trucks during the winter. We use them because they are a portable gasoline-burning heat source that will, with the help of a car battery, start at any temperature.

8.3 Navigating and Surveying

Navigation is no longer the complicated and arcane science that it once was. With the Global Positioning System (GPS) one can now use a palm-sized unit to determine one's latitude and longitude to an accuracy of about 10 m. Before 2 May, 2000, the accuracy was about 100 m, but on that day the US military removed the artificial jitter from the data and gave the world the precision that they had previously reserved to themselves.

Getting from one place on the world to another is now done merely by following the directions given by the GPS unit. However, Arctic pilots still set their gyrocompasses, and they do this either by flying down a runway whose bearing they know or by flying toward the sun and using the sun's bearing. In the Arctic an adequate approximation of the sun's bearing can be calculated by assuming it is 180° at local sun noon and that it changes by 15° every hour. This simple rule of thumb is also used by skidooers who need to know what direction they are headed.

A number of our jobs in the Arctic require the knowledge of elementary surveying. The accurate laying out of an array of hydrophone holes is one example. Determining whether or not the resident ice pan is rotating is another. From time to time we did bathymetry measurements close to shore, and the locations of the measurements were determined with a transit located on shore.

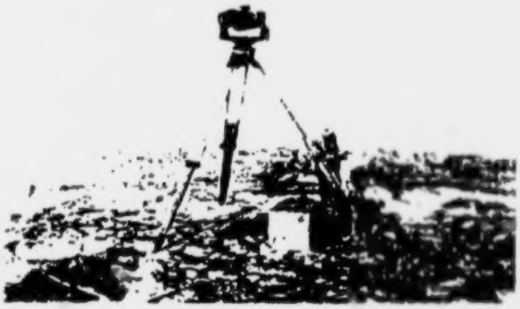

FIGURE 75. Geodimeter set up on a high point of land so that it can survey a large area without being moved.

Our tool for nearly all our surveying is a Geodimeter, Model 140 (Figure 75). As well as being able to measure both horizontal and vertical angles, the Geodimeter can measure distances with its built-in laser range finder. It does this by sending out a burst of light which reflects from a three-corner mirror set up at the site that is to be surveyed. The light is reflected back to the instrument, and the Geodimeter measures the round-trip time and calculates the distance. This distance is reputed to be accurate to a millimetre or two at a range of several hundred metres. An internal computer provides the user with one of three range options: the slant-range distance or either the horizontal or vertical component of this distance.

The Model 140 is fairly old, and it does not have the up-to-date 'bells and whistles for automated data recording. However, it is well suited for cold-weather work. Most importantly in this regard, it has an LED (Light Emitting Diode) display, which is not bothered by the cold. The newer models use LCD (Liquid Crystal Display) displays, which are notorious for freezing up and sometimes becoming permanently damaged at very cold temperatures. The LED display does take more power, but a single charge on a car battery will last for about a week of intermittent surveying.

Mechanically, too, the Geodimeter works well in the cold. It has two axes of rotation, and they rotate as smoothly at -40° as they do at room temperature. The instrument is, indeed, a pleasure to use - other than the fact that one freezes almost to death huddled motionless while peering through the eyepiece and trying to see through eyes that are weeping in the wind. Moreover, one dares not breathe while taking a reading since the eyepiece will instantly ice up. Even moisture from one's eye will cause the transit eyepiece to cloud over slowly.

One of the problems of surveying in the Arctic (as everywhere else) is getting an accurate bearing. In other words, "where is north?" The magnetic compass does not work well in most parts of the Arctic, and, even if it did, it would not provide sufficient accuracy for much of our work. The North Star is of no use since the stars never come out in the spring or summer.

The sun, however, provides an accurate and convenient means of obtaining a knowledge of true north. All that is required is a sun sight and a calculation of the true bearing of the sun at the time of the sight. In principle, one notes the time when the sun is on the cross-hairs of the Geodimeter. One then computes the bearing of the sun and compares that with the reading on the Geodimeter's azimuth circle. The difference gives the correction that must subsequently be added to the Geodimeter's azimuth to obtain the true bearing of whatever the Geodimeter is looking at.

Let us look first at the process of taking the sun sight. First of all, it is important to note that one should never actually look at the sun with this or any other telescope without interposing a dark filter somewhere along the optical path. The amount of light gathered by the objective lens could seriously damage the eye - perhaps blind it. As it happened, we never had a dark filter, so we projected the sun's image onto a piece of paper held several inches behind the eyepiece. We got used to this technique, and we never bothered with the dark filters.

The operator hunts for the sun's image by moving the telescope back and forth and up and down until a bright spot of light illuminates the paper. He/she then adjusts the focus of both the sun's image and the cross-hairs on the paper screen. It is immediately apparent that the sun's image is moving smoothly across the cross hairs. It is also obvious that knowing just when the cross hairs are centred on the sun's image would be very difficult. (How does one find the centre of a circle quickly?) It is much more accurate to note the instant when the vertical cross-hair is on the edge of the sun's image. With this in mind, the operator turns the Geodimeter so that it leads the sun slightly, and he records the time when the leading edge of the sun crosses the vertical cross-hair. Then (without moving the Geodimeter) he waits approximately two minutes until the trailing edge of the sun is in line with the vertical cross hair. After noting this time, the surveyor averages the two times to get a good approximation of the instant that the centre of the sun was on the vertical cross-hair. Later, the sun's bearing will be computed for this instant and will be compared with the Geodimeter's horizontal azimuth, which the diligent surveyor does not forget to write down. It is good practice to take three or four of these sightings partly to confirm that no foolish mistakes were made. Also, the scatter in the values will give the operator an idea of the intrinsic error of the measurement and will let him know what accuracy he can ascribe to subsequent measurements.

Knowledge of the correct time is important. Each minute of error will introduce an error in bearing of approximately one quarter of a degree or about half the sun's diameter.

Accurate time may be obtained from radio station WWV, at 5, 10 and 15 MHz. Even easier these days is to use obtain the time from a GPS receiver. Once the receiver is locked on to several satellites and is providing an accurate position, the time that it displays is accurate to nanoseconds. The usual practice is to compare one's watch with the GPS clock and determine the correction to be applied to the watch.

Next, let us look at the calculation of the bearing of the sun. The 'Arctic' rule of thumb says the sun is in the south at local noon and that it increases its bearing by 15° every hour. This however, is strictly a rule of thumb. The number it gives can be as much as three degrees in error, which is not good enough for our purposes. To obtain fractional degree accuracy the position (*i.e.* latitude and longitude) of both the observer and the sun must be known at the time of the observation, and the bearing must be calculated by spherical trigonometry. Traditionally, mariners use 'Publication 229, Sight Reduction Tables for Marine Navigation' to compute the sun's azimuth for a given location and time. This, however, requires a triple interpolation. Given the availability of laptop computers, a faster method is to calculate the bearing with a spreadsheet program. A discussion of the spherical trigonometry involved and the information that needs to be stored in the spreadsheet is given in Appendix C.

The expected accuracy in bearing can be estimated by doing a number of sun shots scattered throughout the day. Our experience indicates that the bearings should be good to within one or two minutes of arc.

8.4 Tools

The tools one takes to the Arctic are determined by the jobs that are anticipated. Building wooden structures demands quite a different set of tools than does fixing snowmobiles. Expense, weight and storage are considerations that minimize the number of tools. On the other hand, the convenience of having the right tool (and perhaps a spare or two) is a strong motivation for having a large collection. As with tool accumulations anywhere, compromises must be made.

The cold is a factor to be considered when buying power tools. Battery-operated tools tend to be almost useless in the extreme cold. (See the discussion in Section 5.2.2 on using a car battery instead of the internal batteries.) Power tools running off 110 Volts work well enough, but the insulated power cord on many tools (especially cheap ones) will become brittle in the cold. All electrical cords should be tested in the cold before they are taken north.

When it comes to personal tools that we carry in our parka pockets, some of us have rather strong opinions. A pair of seven-inch Visegrips is the number-one choice. The number of jobs that it can do is legion. It can act as a set of steel fingers, as a clamp, as a press and as a wire cutter. It can even be used as a wrench. There are not many fuel drums in the Arctic that cannot be opened with a pair of Visegrips. Many of us have had to give Visegrips the credit for getting us home from a snowmobile outing. We have put on a new drive-belt with Visegrips; we have steered the snowmobile with Visegrips when the steering column has broken, and we have used Visegrips to fix a broken ski temporarily. The list of uses goes on and on. Jim Milne has a saying that is only a slight exaggeration, 'Anybody going skidooing without his Visegrips has a death wish.'

One year we were about 100 miles from the North Pole, and we had just used Visegrips for an emergency replacement of the hinge-pins in the outer door of a military Twin Otter. After taking off from the ice, we heard the following conversation between the two pilots. 'Have you noticed those DREP guys take Visegrips everywhere they go?', said the first pilot. 'Yeah', said the other, 'and next year I will, too'.

The other tools that we carry almost everywhere are a knife and a multi-bit screwdriver. A length of good nylon rope or a 'Herc strap' is something else that should not be far away. It can be a god-send if you or your partner get stuck in rough ice with a skidoo - especially if you are pulling a load.

8.5 Ropes

An Arctic expedition uses rope for many purposes. For example, it is used for lashing loads to a sled, for guying tents to the ice and for hoisting drills out of the ice.

The many different types of available ropes have quite different properties, and a survey of their properties can be found in the Admiralty's Manual of Seamanship[21]. We make very little use of the natural (*i.e.* vegetable) fiber ropes such as manila, sisal, hemp or coir. Rather, we use the man-made fibres - mainly polypropylene and nylon. The only natural cordage we use is sash cord, which is made of cotton.

The properties that vary from type to type are strength, elasticity, resistance to rot and to weather, tendency to twist and tangle and its ability to hold a knot. The expense of the rope is a fairly minor consideration since we use relatively small amounts of it. Polypropylene is inexpensive and strong, but it has many disadvantages. For starters, it does not hold a knot well. A bowline in polypropylene rope, for example, will open itself up unless the rope end is taped down or otherwise tied in place. Secondly, polypropylene rope is usually twisted in construction, which means that the rope twists and tangles easily. It is stiff, which means that it will not flake well into a bucket. Finally, it reacts to ultraviolet light, which means that it will weaken appreciably if it is left for a season out in the sun.

Our favourite type of rope for most purposes is braided nylon, such as Samson Braid. It is strong; it does not twist up; it is soft for flaking into a bucket, and it holds a knot well. It is reasonably elastic, which for most purposes is an advantage. Its principal disadvantage is its expense.

Occasionally we want rope or light cord that has a very low elasticity, and for this purpose we use Kevlar.

In the past we used sash cord to tie loads to sleds. It is soft and flexible and takes a knot very well. However, it is made of cotton, and it is relatively weak. Sash cord should never be subjected to a large load, particularly if someone might be hurt if it broke. Moreover, we seldom use sash cord any more for tying down loads. Cargo straps (or Herc straps as they are commonly known) have taken over this function.

9.0 Concluding Remarks

This manual has described and discussed many of the things we have learned about living and working in the Arctic. Hopefully, in the morass of detail several over-riding principles have stood out. The first is to foster reliability by keeping things as simple as possible. Simple equipment and simple techniques tend to have had the problems worked out of them, and if they do develop problems they are more apt to be fixable at an ice site.

It is not easy to design simplicity into equipment or into a procedure. First designs are almost always more complicated than they need be. It takes hard work, a lot of discussion and a healthy dose of scepticism to achieve the elegance of simplicity.

Another important principle is to assume - until proven otherwise - that anything new and untested will not work in the cold. Plastics, in particular, are notorious for becoming brittle and breaking in the cold. Seals (*i.e.*, O-rings) may need to be changed, and bearings may need to be de-greased. It is important to 'cold-soak' anything new for several hours at -40° C and then see if it works adequately.

Anything mechanical should be designed so that it can be assembled and disassembled by someone with gloves on. This means that nothing small and dainty (small bolts, for example) should be used in the design. Whenever possible, clearances should be grossly large; something with a 1 or 2 thou' clearance will just not go together if someone breathes on it.

Use a lot of common sense, especially around equipment that could hurt you.

Enjoy the experience, and make sure everyone else does, too.

10.0 Acknowledgements

I would like to acknowledge the many people at DREP and its previous incarnation, PNL (Pacific Naval Laboratory), who have contributed to the fund of Arctic expertise. Beginning in the late 1950's and into the 1960's, Allan Milne and John Ganton made the lab's first scientific trips to the Arctic. They were assisted by people such as Dick Herlinveaux, Tom Hughes, Borge Haagensen and Ted Jackman. These, if you will, are the old-timers who started it all and who are now retired. More recently, people like Jon Thorleifson, Mervin Black, John Ozard, Gary Brooke, Stan Dosso, Jim Kennedy, Gordon Ebbeson, Jim Perkins, Dave Baade, Jim Milne, Steve Taylor, Brendan Donald, Colin Ganton, Darryl Gittins, Bob McLean, Linda Churcher, Dave Berger, Del Huston and Bob Rodger have spent many years at DREP developing procedures, both scientific, technical and logistical. Taken as a group, they have a tremendous fund of experience and knowledge. It has truly been a pleasure working with such intelligent, inventive and affable people. It is particularly poignant that all of them, except one or two, have left the Arctic group since DREP was closed, and most have left the government service entirely. I wish them well.

There have been many Canadian Forces officers seconded to DREP. One of their roles was to help us with logistic matters such as obtaining aircraft support - Hercules, Twin Otters, helicopters, etc. Although all were very proficient at their job, some took a particular interest in the technical problems of doing science in the Arctic. Even though they were at the lab for only two or three years, they made a significant contribution to the development of equipment and techniques. In this regard I would like to acknowledge Capt Stannard Toole, Capt Don Lowdon, LCDR Peter Lenk, LCDR Tudor Davies and Capt Richard Van Der Pryt.

I take particular pleasure in thanking Dorothy Edwards, who was the first to suggest that a manual like this was needed. In fact, she did more than suggest; she argued for it long and hard.

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Appendix A: Appropriate behaviour around polar bears.

This discussion has been taken from the Polar Shelf operations manual, as given in their web site: http://www.nrcan.gc.ca/ess/pcsp/profpage/opsman/opsman_e.htm

In the presence of bears:

· remember that polar bears behave unpredictably, therefore expect anything and be prepared for it;

· avoid contact with bears if possible; there is no point in risking your life;

· do not sleep in the open, without a tent;

· minimize the number of tents in a camp. A few large tents are better than a lot of small tents. Place them in line or in a semi-circle with enough space between them for easy escape by a bear that may wander through camp;

· maintain areas for cooking and food storage at least 100 to 200 metres away from sleeping areas. NEVER keep food in your sleeping tent;

· burn garbage several hundred meters away from camp in an area visible from camp;

· keep a clean camp - grease and greasy foods will attract bears; they can smell cooking food for miles;

· never leave camp alone;

· a dog can serve as a useful bear alarm. The dog probably will alert you to the presence of a bear, but will not frighten it away;

· most bears are frightened by helicopters or snow vehicles. When chasing a bear on a snow vehicle, stay about 30 meters behind it to give the impression that it can outrun you. If it is crowded, it may turn to fight.

· If no vehicle is available, fire shotgun shells or flares overhead, or to one side.

· When the bear approaches to within 50 meters, a warning shot behind or beside it might scare it. Do not fire between its legs because a ricocheting bullet could badly injure the animal;

· bears are inquisitive. Give them a chance. Shoot to kill only as a last resort. If the bear continues to approach, keep making noise, but do not run. Stand your ground. Be prepared to shoot only if the bear charges. Run only if you are sure you can make it to safety.

· a bear will exhibit signs of annoyance by making a hissing sound, lowering its head while facing you, or making a small rush (4 to 10 paces in your direction) then stopping. At, or before, any of these signs, there is still time to back out of the situation. You will probably require at least 50 meters distance from the bear.

· BACK OUT SLOWLY, facing the bear. At ranges of less than 50 meters, it may be better to stand your ground. A bear usually charges at high speed, and low crouched over the ground, like a cat rushing a bird;

· it is important that your first shot drops a charging bear, since there may not be time for a second shot. Aim for the main front shoulder area or low neck-shoulder region where a hit will break important bones and drop the bear.

Appendix B: Emergency Sled Contents (24 Person-Days)

2 Moss tents
2 shovels, snow knife set
rope
garbage bags, black - for markers
marker flags
2 4-quart pots
toilet paper
2 sheets space-therm insulation

Note: sleeping bags and bamboo poles can be attached to outside of sled.

Instruction is required to use this kit - especially to put up tent. Check fuel, matches and food. Kit DOES NOT contain sleeping bags.

Radio and tool box contents

ELT Beacon with 2 spare GS 21 batteries
HF Radio and antenna
Tools: Vice grip screwdriver and Olfa knife
Signal mirror.
ELT headset and mic.
9 spare D cells
Note pad and pencil

Note: Antenna can lie flat on snow but is better with centre elevated. Polarity of connector does not matter.

Stove boxes - contents

1 MSR Stove per box
5 fuel bottles & filter naphtha/box
Heat reflector and wind screen.
#212 silicone O rings
Waterproof matches
Fuel filter/funnel
Spare parts kit

Note: Check O-ring condition of fuel bottles and pump.

Food Boxes (two) - Content of each box.

Food - 12 person day supply/box
3 sets plastic cutlery per box
3 plastic cups per box
zip lock bags.

Note: Add as much extra food as space will allow inside sled.

First Aid box - Contents

10 Anti Bacterial towelette, Bentadine
100 ASA
2 Bandage pressure (military
1 Bandage, tensor 3"
1 Antiseptic ointment
1 Bandage, gauze 3" x 5 yd
2 Bandage, tensor 2"
3 Bandage, triangle

1 Dressing, large injury/abdominal pad
6 Dressing, telfa 2" x 3"
1 Q tips
1 Scissors
1 Tape, adhesive medical waterproof
10 towelette, antiseptic

Band Aids
6 Dressing, Telfa 3" x 4"
1 Safety pins
7 Steri-strips
Tape, surgical 3M transpore 1"

Appendix C: Calculation of the Sun's Bearing

This appendix gives a short summary of spherical trigonometry and its use in computing the sun's bearing. It also discusses how to store the sun's ephemeral parameters in a way that can be used efficiently by a computer spread sheet.

The basic steps to using spherical trigonometry are:

- Learn the definition of a spherical triangle and its various parts.
- Identify the parts of the triangle with real-world entities.
- Given three of the six parts of the triangle, learn how to compute the others

Figure C1 represents a sphere with a spherical triangle drawn upon it. By definition, each side of the triangle is part of a great circle. The length of the side is measured in angular measure (degrees or radians) - not in linear measure. The relevant angle is measured at the centre of the sphere between the lines extending from the centre to the two points. Thus, side 'b' is the angle between rays going from the centre of the sphere to points 'A' and 'C'. The length in angular measurement can, of course, be converted to linear measure if the radius of the sphere is known.

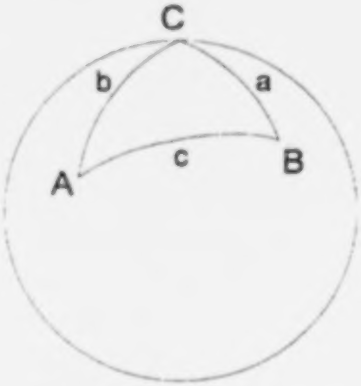

FIGURE C1. A typical spherical triangle.

The 'angles' of the triangle, 'A', 'B' and 'C' are a measure of the dihedral angle between two planes. Angle 'A', for example, is the angle between the planes ACO and ABO, where O is the centre of the sphere. Imagine yourself standing at A (on the earth's surface) and facing B. As you turn to face C the angle through which you turn is the angle 'A'.

We will need to 'solve' the triangle in which we know two sides and the included angle, 'a', 'C' and 'b', for example. The cosine formula, whose derivation can be found in any spherical trigonometry book, gives the opposite side 'c'.

$$\cos(c) = \cos(a)\cos(b) + \sin(a)\sin(b)\cos(C)$$

This formula yields an angle 'c' that lies between 0 and 180°. There is no ambiguity here. Angle 'c' will never be greater than 180° since, by definition, the side of a spherical triangle is always less than or equal to a half circle.

Once one has all three sides, 'a', 'b' and 'c', the above formula (with the variables permuted) can be used to solve for the angles 'A' and 'B'. For example,

$\cos(A) = (\cos(a)-\cos(b)\cos(c))/(\sin(b)\sin(c))$, and similarly for 'B'.

The next step is to associate real-world entities with the parts of the spherical triangle. In nearly all navigation problems, one of the vertices of the triangle is at the north pole. In Figure C1, the vertex C takes this role. The vertex B is taken to be at our location - where we are making the sun sight. The vertex A is the spot on the earth's surface that is perpendicularly under the sun at the time of the sight.

Side 'a' is the angle measured from the North Pole to our location. Thus, it is 90^o minus our latitude. Similarly, side 'b' is the angle measured from the Pole south to the position directly under the sun. It is 90^o minus the sun's 'declination' (which is what the sun's latitude is called). Note that south latitudes and south declinations are treated as negative quantities.

The angle 'C' is the difference in our longitude and the longitude of the spot directly under the sun. The longitude of the sun is called the Greenwich Hour Angle (GHA). (It is convenient for us to take west longitude as being positive since it then has the same sign as the GHA.) The angle 'C' and the two sides 'a' and 'b' are the 'knowns' in our calculation.

Side 'c' is 90^o minus the sun's elevation. If, for example, the sun is directly overhead, its elevation would be 90^o and side 'c' would be zero. This element of the triangle is not used in what follows, whereas it is very important in sextant work.

The angle 'B' is the angle at our position between true north and the sun. Thus, it is the bearing of the sun, which is what we want to calculate. Of course the sun may be either east or west of the meridian, and so its bearing may lie between 0 and 180^o or it may lie between 180^o and 360^o. The cosine formula is ambiguous on this point, and the ambiguity must be removed by the following considerations.

Figure C1 intimates that when the sun's GHA is larger than the observer's longitude, the bearing will be greater than 180^o; otherwise the bearing will be less than 180^o. This is not quite correct, however. The proper quantity to examine is the sin(GHA - longitude). If this quantity is positive, the sun's bearing will be greater than 180^o; if it is negative the bearing will be less than 180^o.

In order to do the calculation we must obtain the two latitudes and longitudes. The position of the observer is easily obtained from GPS. The position of the sun, on the other hand, is a little harder to determine.

The Nautical Almanac, issued yearly by both Washington and London, has all the required information. The sun's declination and GHA is tabulated for every hour of the year. The declination changes slowly, going from 23.5° S to 23.5° N in six months. The GHA, on the other hand changes quite rapidly - approximately 15° per hour or 360° per day. If we were to do the computation by hand, we would extract the appropriate declination and GHA from the Nautical Almanac (making interpolations, if necessary) and enter them into the appropriate formulas (or use 'Publication 229, Sight Reduction Tables for Marine Navigation'). On the other hand, if we wish to have a spreadsheet do the computations for us, we would really like to have the Almanac information pre-entered as a Table. However, entering values for every hour is not practical. Nor is it necessary; it is possible to keep the table size quite small.

The sun's declination (latitude) changes so slowly that a table entry for every four days is sufficient for a spreadsheet calculation. A linear interpolation between consecutive entries gives good accuracy. Thus, as far as the declination is concerned, there is no problem in keeping the table size small.

The Greenwich Hour Angle, one might think, should be even easier. It changes 15° every hour, and it should be easily calculated by the spreadsheet. However, life is not quite so simple. Although the earth spins at a constant rate, and the length of the sidereal day is constant, the period between noon and noon is not always 24 hours - if noon is defined as being when the sun is on the meridian (due south). Remember that because the earth is rotating around the sun the earth must turn through slightly more than 360° between sun noon and sun noon, and it is the variation in this extra amount that causes the present difficulty.

There are two contributing factors. First, the earth's orbit around the sun is an ellipse and not a true circle. When the earth is close to the sun its orbital speed is higher, and this means the earth has to rotate through a larger than average angle in going from noon to noon. And, of course, when it is far away, it must turn through a smaller than average angle. Secondly, even if the earth's orbit were a true circle the period from noon to noon would not be constant. This is a consequence of the plane of the orbit not being in the plane of the equator. Let us compare the motion of the earth at the equinoxes with its motion at the solstices. At the equinoxes, when the sun is on the equator, the earth's motion about the sun has an appreciable north-south component and less of a component in the plane of the equator. It is the component of the earth's motion parallel to the plane of the equator that governs the extra angle through which the earth must turn between sun noon and sun noon. Since this component varies, the length of the solar day must vary.

For the sake of convenience, navigators postulate a fictitious body called the 'mean' (or average) sun. This perfect sun is always due south at the local (sun) noon, and its *GHA* changes at exactly 15° per hour. The time that must be added to the GHA of the mean sun to get the GHA of the true sun (the one you must not look at) is called the 'equation of time'. For convenience these 'corrections' (the equation of time) are tabulated in the Nautical Almanac. The almanac indicates that the true sun can be as much as 14 minutes (of time, not angle) early or late in arriving at the due-south point.

It is now evident how our spreadsheet can calculate the GHA of the sun. It is the sum of two parts, the GHA of the mean sun, which is rapidly changing but easily computed, and the equation of time, which must be looked up in a table but which is slowly changing. A tabulated value for every fourth day is sufficient to give good accuracy if linear interpolation is used.

The spreadsheet is set up to have provision for entering one's latitude and longitude, the date and the time (Greenwich Mean Time). Using the date and time the spreadsheet will do a table look-up and interpolation to obtain the sun's declination and GHA. It then does the spherical trigonometry calculations to obtain the sun's bearing. Prior to the field trip, the spreadsheet is loaded with a table of declinations and equation-of-time values for the period of interest. In practice, the previous year's spreadsheet is simply modified to reflect the new declinations and equation of time.

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For more than thirty years scientists and technicians from the Defence Research Establishment Pacific (now defunct) went to the High Arctic to do underwater acoustics research. During these years they developed many tricks and techniques for living and working on sea ice, and this document describes many of them. There are sections on transportation, safety and coping with the cold. Part of the document discusses sea ice: how to gauge its age and thickness, and how to establish temporary camps on it. A large section discusses the many ways of making and maintaining holes through the sea ice - with both mechanical drills and hot-water drills. Another section describes a number of techniques for installing equipment through the ice and getting it back. The manual describes in some detail the use of equipment such as snowmobiles, tracked vehicles, gas- and Diesel-powered generators, HF radio, VHF radio, repeaters, stoves, hot-water drills and remotely operated underwater vehicles.

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